PROGRAM
for a set of preliminary investigations (Phase I) in preparation to a Full Scale Gamma-Ray Lasing (GRL) Experiment (Phase II)

Principal Investigator:
Lev A. Rivlin

MIREA Technical University

78 Vernadsky Ave., Moscow, 117454, RUSSIA
Phone: +7 095 434 7247. FAX: +7 095 434 9317
E-mail: <rla@superlum.msk.ru>

FINAL TECHNICAL REPORT
Nov. 5, 1999 through June 5, 2000
prepared for European Office of Aerospace Research and Development
Project: SPC-00-4002. Contract: F61775-00-WE002

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	7 June 2000	Final Report, November 1999 – June 5, 2000

4. TITLE AND SUBTITLE

Program for a Set of preliminary investigations (Phase 1) in Preparation for a Full Scale Gamma-Ray Lasing (GRL) Experiment (Phase 2).

5. FUNDING NUMBERS

F61775-00-WE002

6. AUTHOR(S)

Lev Abramovich Rivlin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

MIREA Technical University
78 Vernadsky Ave
Moscow 117454
Russia

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES

EOARD
PSC 802 Box 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC 00-4002

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

ABSTRACT (Maximum 200 words)

This report results from a contract tasking MIREA Technical University as follows: The contractor will develop a plan of an experimental program for developing and demonstrating the basic technologies that are necessary to make an intense, directional gamma-ray source.

14. SUBJECT TERMS

EOARD, Gamma ray emission, Gamma ray lasers

15. NUMBER OF PAGES

74

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

1

The Contractor, MIREA Technical University, hereby declares that, to the best of its knowledge and belief, the technical data delivered herewith under Contract # F61775-00-WE002 is complete, accurate, and complies with all requirements of the contract.

Date: June 2, 2000

A.S. Sigov, Professor and Rector of the MIREA Technical University

2

I certify that there were no subject inventions to declare as defined in FAR 52.227-13, during the performance of this contract.

Date: June 2, 2000

A.S. Sigov, Professor and Rector of the MIREA Technical University

MIREA
Tech U

Abstract.

This Final Technical Report (Nov. 5, 1999 through Jun. 5, 2000) includes the detail Program for a set of preliminary investigations leading to the Full Scale Nuclear Gamma-ray Lasing (GRL) Experiment based on the Concept of Recoil Assisted GRL which was developed under EOARD Project SPC 99-4036 (Contract # F61775-99-WE036).

Contents

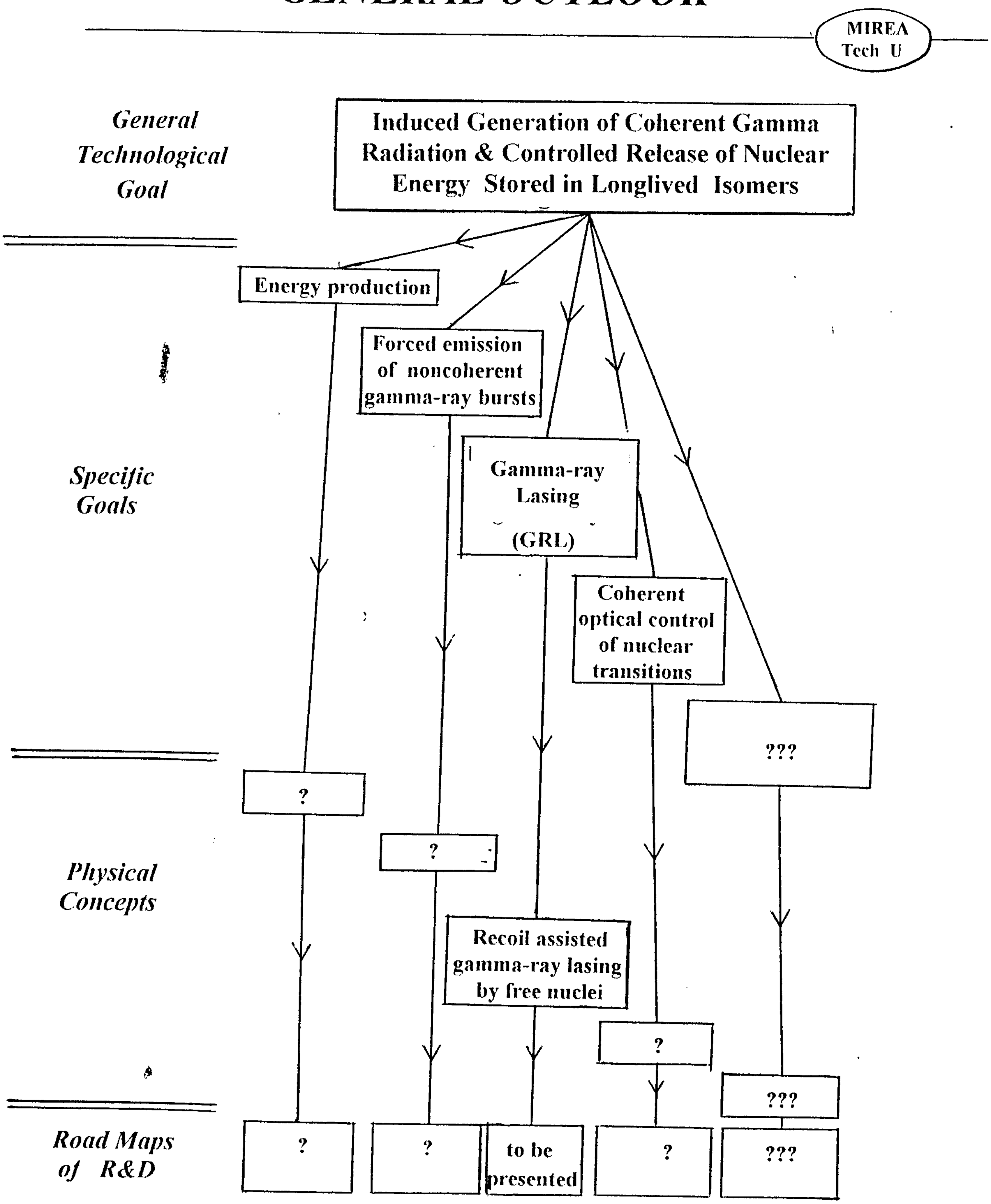
«State» Road Maps

23. Road Map of R&D («State» routs: 3.1)
    = Elaboration of general scheme of cooling and trapping processes
24. Road Map of R&D («State» routs: 3.2)
    = Development of special optical lasers for atom cooling and confining
24. Road Map of R&D («State» routs: 3.3)
    = Development of optical system for deep cooling dense atom medium
25. Road Map of R&D («State» routs: 3.4)
    = Development of setup to form and cool dense fiber-like atom beam and load it into trap
26. Road Map of R&D («State» routs: 3.5)
    = Development of extended trap to confine a fiber-like dense atom beam
27. Road Map of R&D («State» routs: 3.6)
    = Construction and test of entire system for cooling and trapping dense atom medium
28. Road Map of R&D («State» routs: 4.1 and 4.3)
    = Experiments with various kinds of X-ray machines and evolution of their spectral density data & Choice of optimal pumping process and X-ray source
29. Road Map of R&D («State» routs: 4.2)
    = Experimental research of triggering anti-Stokes transitions, etc.
30. Road Map of R&D («State» routs: 4.4 and 4.5)
    = Development and construction of online diagnostic and control & Development and construction of X-ray pumping source(s)
31. Road Map of R&D («State» routs: 4.6)
    = Development of X-ray optical system for filtering, collimating and transportation of pumping radiation
32. Road Map of R&D («State» routs: 4.7)
    = Construction and test of entire pumping system
33. Road Map of R&D («State» routs: 6.1 and 6.7)
    = Launching entire system for cooling, loading, and trapping of atom medium & Adjustment of online diagnostic and control system
34. Road Map of R&D («State» routs: 6.2-6.6 and 6.8)
    = Measurements of loading system efficiency. Measurements of atom velocity distribution (3D) («temperature»). Measurements of longitudinal transport velocity of atom beam. Measurements of atom beam density and transverse size. Test of atom trap stability. Evolution of main experimental parameters of entire system for atom medium cooling and trapping.

35. Road Map of R&D («State» routs: 7.1,7.5 and 7.6)
    = Launching entire pumping setup including X-ray machine and related arrangements. Adjustment of online diagnostic and control system. Test of reproducibility of pumping process.
36. Road Map of R&D («State» routs: 7.2-4 and 7.7)
    = Measurements of spectral density and time dependence of pumping X-ray flash. Measurements of Efficiency of X-ray optical filtering and transportation of pumping radiation. Measurements of quantum efficiency of anti-Stokes and «two-level» schemes of pumping processes. Evolution of main experimental parameters of X-ray pumping system.
37. Road Map of R&D («State» routs: 8.1,2)
    = Assembling and launching entire system including atom cooling/trapping and X-ray pumping setups. Adjustment of online diagnostic and control system.
38. Road Map of R&D («State» routs: 8.3)
    = Test of quantum efficiency of pumping cooled and trapped nuclei ensemble.
39. Road Map of R&D («State» routs: 8.4)
    = Test of non-invasiability of cooled and trapped atom beam undergoing X-ray pumping.
40. Road Map of R&D («State» routs: 8.5,6)
    = Test of compatibility of combined cooling/trapping & X-ray pumping system. Evolution of main experimental parameters of combined cooling/trapping & X-ray pumping system.

41. Tentative time & funding schedule.
42. Comments to Tentative funding schedule.
43. The bottom line
44. References

GENERAL OUTLOOK



1. Introduction and General Physical Concept

MIREA
Tech U

This ***Program*** is a development and extention of the general Concept of Recoil Assisted Nuclear Gamma-ray Lasing elaborated in 1999 under EOARD Project SPC 99-4036 (Contract # F61775-WE036) [1]. The heart of this Concept (which must be considered as an indefeasible part of the ***Program***) is a deliberate use of the recoil of free nuclei accompanying any event of absorption or emission of a gamma-ray photon.

General main goal of accomplishment of this ***Program*** is to elaborate the Project of Full Scale Gamma-ray Lasing (GRL) Experiment with detail descriptions and technical specifications. The eventual GRL experimental activity is actually a separate branch of more general big problem of modern Quantum Nucleonics, namely,

INDUCED GENERATION of COHERENT GAMMA RADIATION
&
CONTROLLED RELEASE of NUCLEAR ENERGY
STORED in LONGLIVED ISOMERS

which includes a set of sub-problems like

(a) ***energy production,***
(b) ***forced emission of non-coherent gamma-ray bursts,***
(c) ***gamma-ray lasing (GRL),***
(d) ***coherent optical control of nuclear transitions,***
etc, etc...

Detail exhaustive physical concepts are already elaborated for some of these sub-problems (e.g., for *(c) - GRL*). There are various interesting theoretical proposals regarding another ones which presumably to be evolved into well developed concepts in near future (see, for instance, [11,15]).

As concerns the present GRL ***Program,*** we shall emphasize that [1,2] , the use of nuclear recoil opens up, contrary to the standard scheme of optical lasers, entirely new possibilities inherent exclusively in radiative processes involving sufficiently hard photons:

- the possibility to establish a «hidden inversion» of state populations in an ensemble of nuclei, which appears without excess of the number of excited oscillators over the number of unexcited ones;

- the possibility to accomplish incoherent X-ray pumping of a nuclear ensemble in the «two-level» scheme, which is similar to the known three-level scheme of optical lasers but resorts to only two acting states of the laser transitions without resort to the third auxiliary level;

- the possibility to accomplish non-invasive (non-perturbative) X-ray pumping according to the anti-Stokes scheme;

- the possibility of anisotropic quantum amplification of an unidirectional gamm-photon flux without any reflecting devices;

- the feasibility of internal modulation of photon losses accompanied by emission of an intense gamma-ray pulse, in a sense similar to the giant pulse of an optical laser.

The above-listed and other remarkable features, which facilitate the progress towards the successful Full Scale Gamma-ray Lasing Experiment, reveal themselves only in a laser with free nuclei. That is why the ***Program*** under consideration differs fundamentally from the traditional Moessbauer approach in which nuclei are introduced into a solid matrix. But this circumstance simultaneously creates a need for a radical reduction in the unhomogeneous Doppler broadening of the emission line (which does not occur in the phonon-free solid version) to attain acceptable gain coefficients for the photon flux. This objective is to be accomplished by present-day techniques of deep cooling of atomic ensembles by the light pressure of optical lasers.

We specify some major (but not sole) problems along the path to the Full Scale Gamma-ray Lasing Experiment:

- Selection of optimum candidate nuclides taking into account their nuclear and atomic properties on the basis of theoretical concepts and available databases and, probably, pursuance of additional nuclear spectroscopic research.

- Production and separation of ponderable amount of selected nuclide.

- Development of the devices for the preparation, cooling, and confinement («trapping») of the extended fiber-shaped atomic beam of selected nuclides. Significant rise in atomic density in comparison with that attained to date.

- Development of the X-ray pump sources with equivalent blackbody temperatures of hundreds to thousands of kiloelectronvolts. Development of devices for focusing and transporting the pump radiation to the nuclear beam.

- Provision of mutual operation compatibility of very delicate setups for cooling and confining nuclei bearing atom beam and high power pulsed electric machines for generating X-ray pump radiation.

It is pertinent to note that some above mentioned problems refer to the branches of experimental physics that are now being developed intensively (independent of the nuclear gamma-ray lasing problem), which allows us to look forward to a relatively fast and successful solution of the whole problem. There remains the problem of developing efficient reflectors in the subnanometer wavelength range. The application of such reflectors could radically reduce the requirements imposed on the nuclear density and the length of atomic beams.

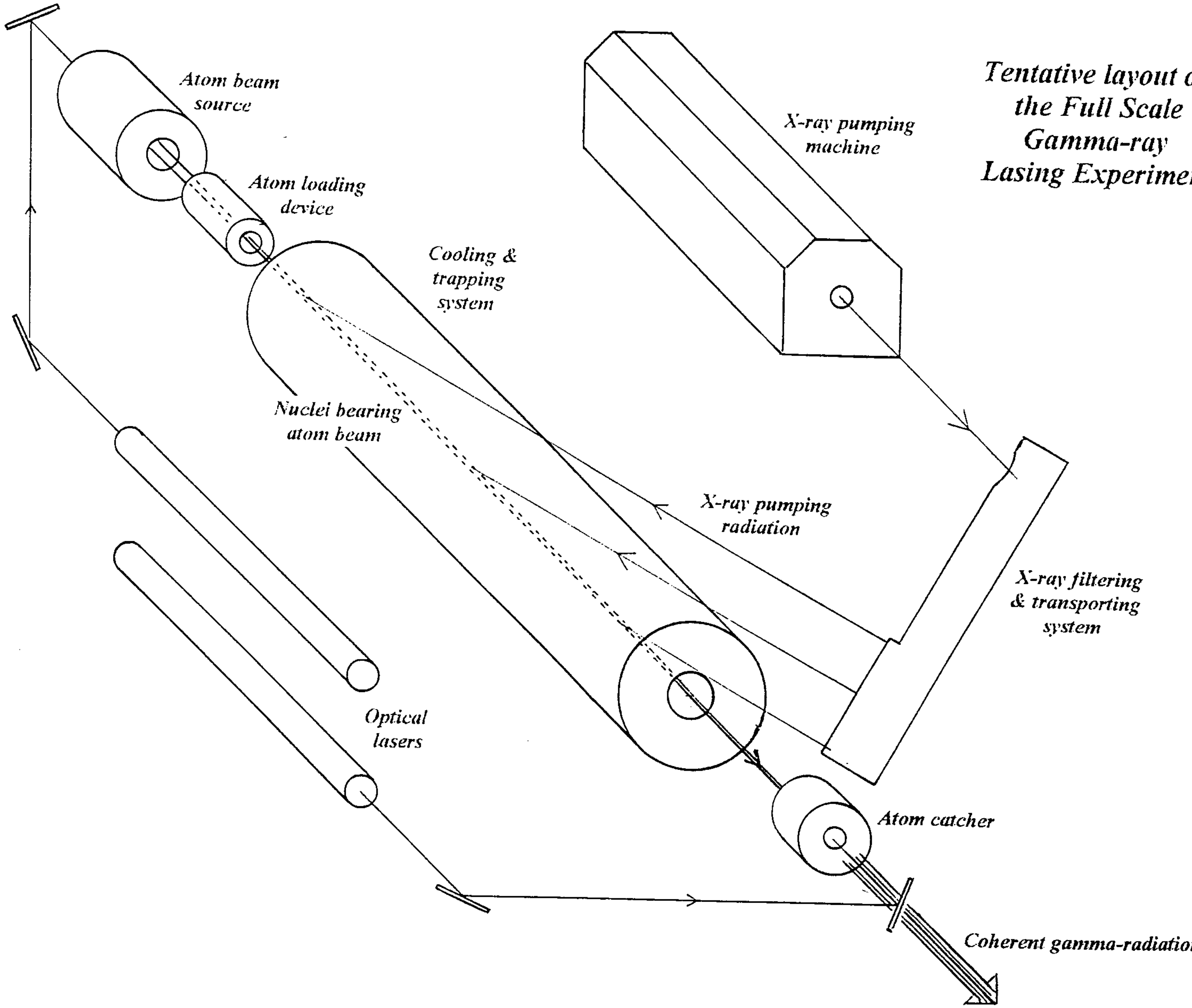
These first-stage experimental problems do not refer in essence to nuclear physics and would not require a hot laboratory. Evidently, the results of these experiments may introduce significant quantitative corrections to the primary ***Concept*** of a gamma-ray laser with free nuclei and the purposeful beneficial use of the kinematic spectral line shift arising from recoil.

The very crude draft (see next page) of tentative layout of the Full Scale Gamma-ray Lasing Experiment serves as an elucidation of aforesaid statements, but by no means as a construction pretending to certain level of completeness. The main constituents of this layout are:

- nuclei bearing atom system which consists of atom beam source, atom loading device, cooling and trapping setup, and atom catcher;
- optical lasers used to cool and trap an atom beam;
- X-ray pumping machine; and
- X-ray filtering and transporting system.

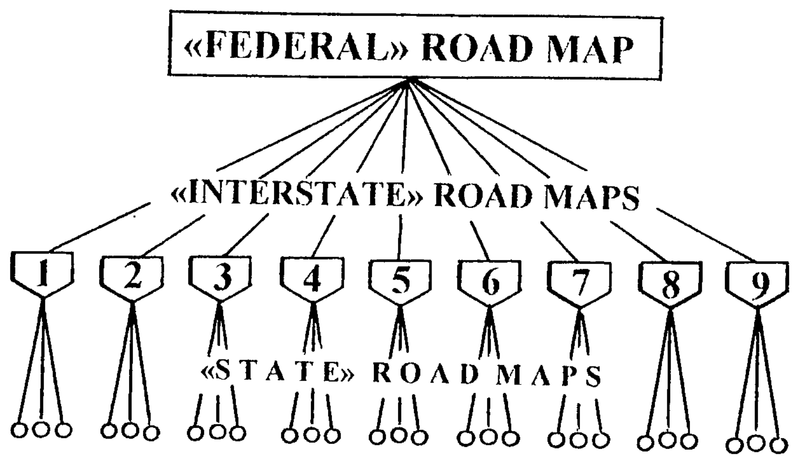
This Final Report has format and structure of a set of road maps («federal», «interstate», and «state» routs according to R&D hierarchy), and detail technical comments with related numerical data. Attached draft of time and funding schedule must be considered only as a some kind of «zero order approximation» because of lack of investigator's experience in this side of American R&D practice.

Tentative layout of the Full Scale Gamma-ray Lasing Experiment



STRUCTURE and HIERARCHY of a SET of ROAD MAPS of R&D

MIREA Tech U

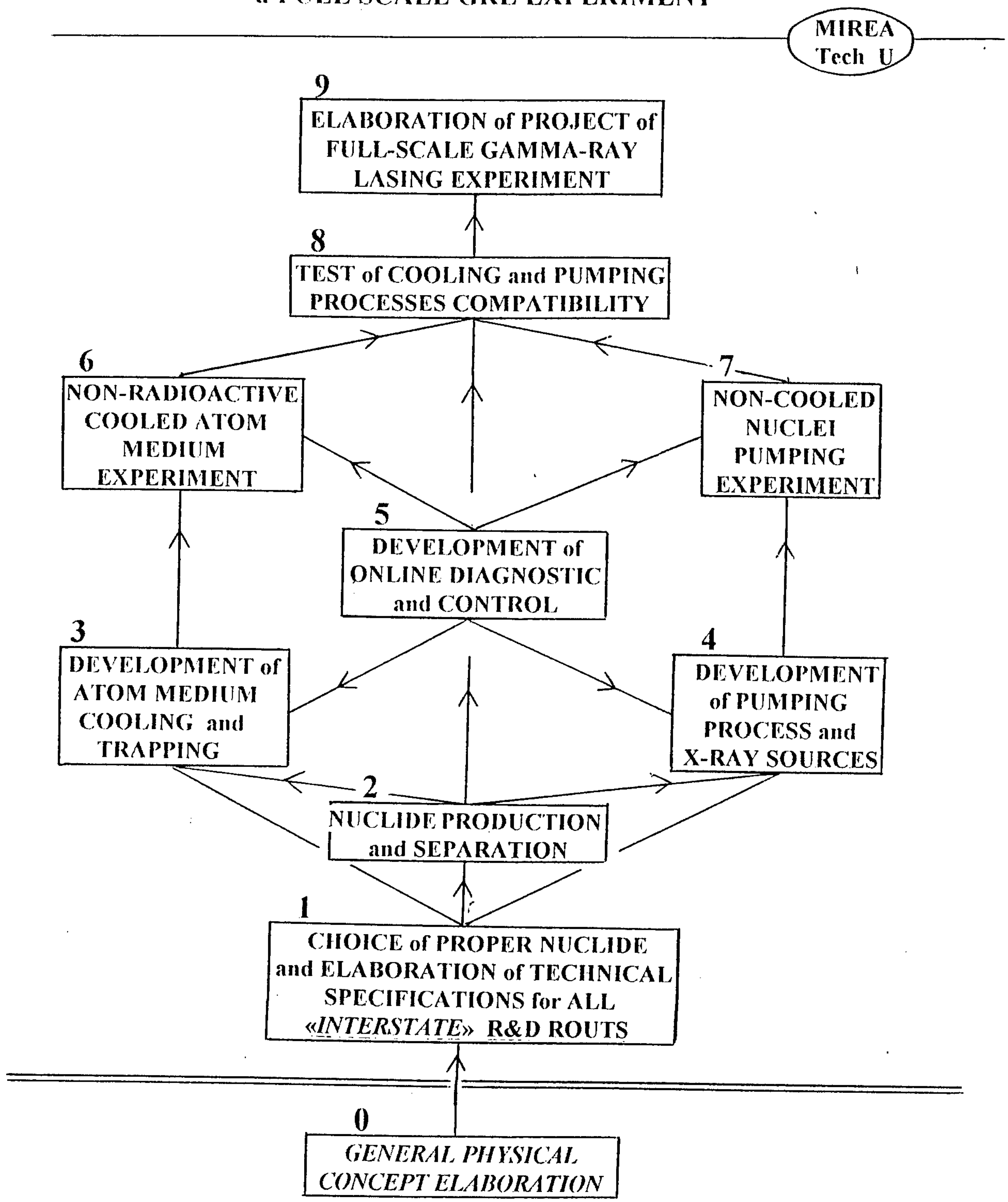


«Federal» Road Map

ROAD MAP of R&D

(«Federal» routs)

PROGRAM of PREPARATION to a FULL SCALE GRL EXPERIMENT



COMMENTS to «FEDERAL» ROAD MAP

MIREA
Tech U

- Position below double line - ***General Physical Concept Elaboration*** - is already fulfilled under EOARD Project SPC 99-4036 (Contract # F61775-99-WE036) [1].

1. ***Choice of proper nuclide and elaboration of Technical specifications for all «interstate» routs.*** Choice of certain nuclide(s) results in necessity to elaborate new Technical Specifications for the entire set of experiments because the preliminary rough data presented in [1] were made for some vague hypothetical nuclide. Both nuclear and atomic properties of chosen nuclide should be taken into account.

2. ***Nuclide production and separation.*** Amount and state of nuclei needed for Experiments # **3,6** and **4,7** are quite different. Experiments # **3,6** are liable to be made with ponderable amount of chosen nuclei in a ground (non-radioactive) state. Experiments # **4,7** need both micro- and ponderable amounts of excited nuclei in metastable state (for anti-Stokes scheme) or in ground state (for «two-level» scheme).

3. ***Development of atom medium cooling and trapping.*** This part of experiments has a firm standby of modern technique of optical deep cooling and manipulating the neutral atom ensembles by laser light pressure [3]. An important task is to increase the atom concentration and the volume occupied by atoms (see Comments to «interstate» road map # **3**).

4. ***Development of pumping process and X-ray sources.*** These efforts break into two main parts: (1) investigations of excitation processes and cross-section measurements which need only low level X-ray sources, and (2) development and investigation of high intensity X-ray pumping sources which usually are powerful big and costly machines. This demands to use in latter experiments existing X-ray facilities (see Comments to «interstate» road map # **4** and Road map of «state» routs # **4.1,3**).

5. ***Development of online diagnostic and control.*** This service system must provide operation and measurements of all separate setups in various experiments and entire experimental equipment, and likewise operation of «safety first» system.

6. ***Non-radioactive cooled atom medium experiment.*** This experiment may use a ponderable amount of chosen nuclide in a unexcited ground state and does not demand a «hot» laboratory.

7. ***Non-cooled nuclei pumping experiment.*** This experiment may use both ponderable amount of nuclei and high intensity X-ray machines. In certain cases it needs a «hot» laboratory.

8. ***Test of cooling and pumping processes compatibility.*** This test is of high importance because there is some fear that operation of full scale pumping setup using high power pulsed electric devices possibly may interfere the atom cooling process which is of exclusively delicate nature.

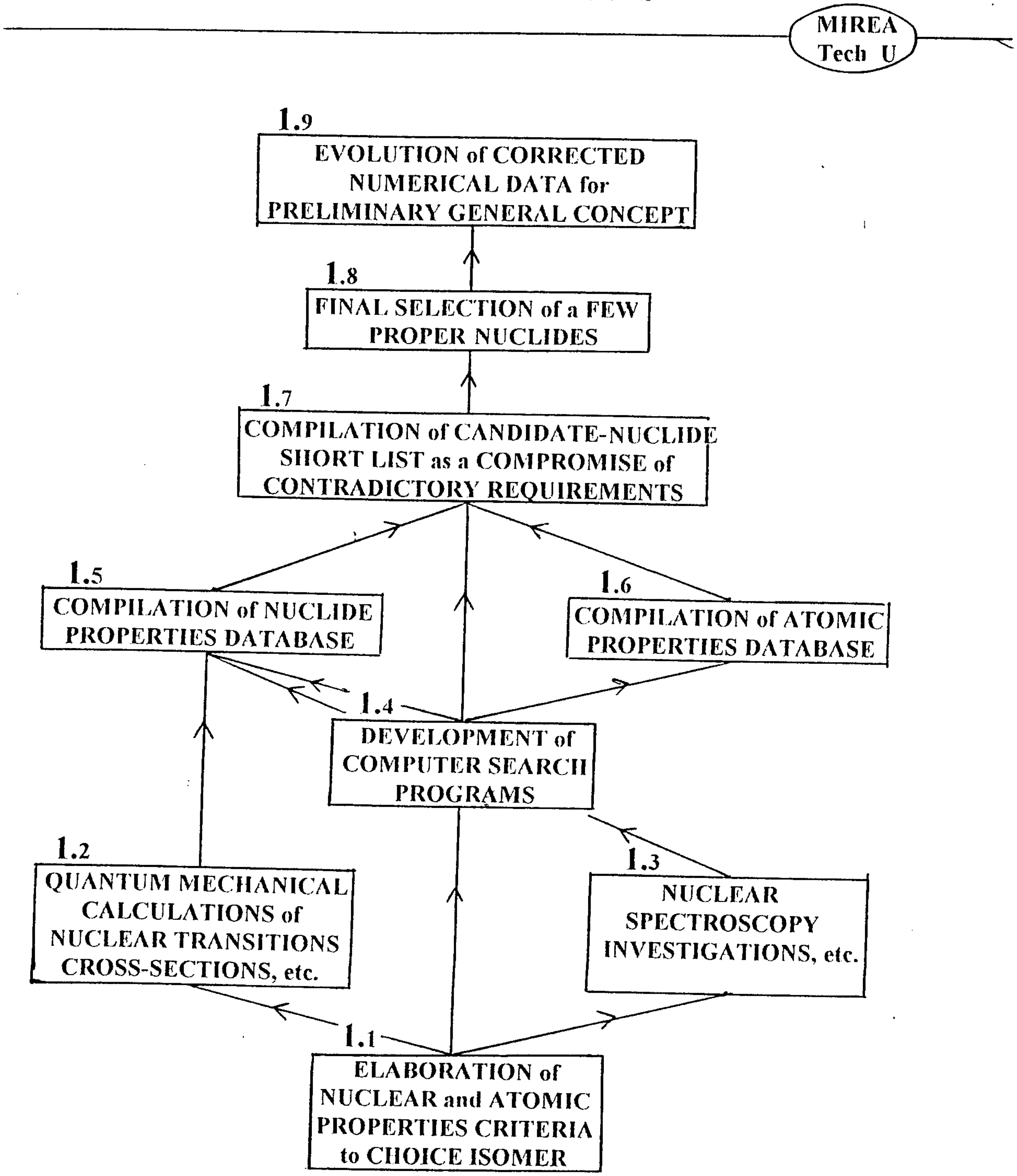
9. ***Elaboration of Project of full scale gamma-ray lasing experiment.*** This last step of the ***Program*** finishes by presenting the construction project of full scale GRL setup accompanied by detail descriptions, technical specifications, and program of further experimental activity.

«Interstate» Road Maps

ROAD MAP of R&D

(«Interstate» routs: 1)

CHOICE of PROPER NUCLIDE and ELABORATION of TECHNICAL SPECIFICATIONS for ALL *«interstate»* ROUTS



COMMENTS to «INTERSTATE» ROAD MAP # 1

MIREA Tech U

GOAL:

To state the nuclear active medium

SOLUTIONS & METHODS:

Computer search.
Nuclear and atomic parameters calculations and measurements.
Stating a set of compromised/optimized parameters.

1.1. ***Elaboration of nuclear and atomic properties criteria to choice nuclide.***

Some examples of nuclear criteria: proper anti-Stokes level structure; upper limit of trigger (say, 2 keV) and laser (say, 100 keV) transitions energy; lower limit of metastable state lifetime (say, 1 month); upper limit of laser transition energy (say, 5 keV) and optimal lifetime range (say, nanoseconds) for «two-level» scheme; upper limit of internal electron conversion coefficient; *etc.*

Some examples of atomic criteria: proper atom level structure and transition cross-section adequate for laser light absorption; *etc.*(see, for instance, [3]).

1.2. ***Quantum mechanical calculations of nuclear transitions cross-sections, etc.***

1.3. ***Nuclear spectroscopy investigations, etc.***

Both theoretical and experimental investigations are directed to cover existing lack of corresponding data on transition line widths, lifetimes, cross-sections, coefficients of internal electron conversion, and so on.

1.4. ***Development of computer search programs.***

1.5. ***Compilation of nuclide properties database.***

1.6. ***Compilation of atomic properties database.***

Computer work which lays firm quantitative ground for all further activity.

1.7. ***Compilation of candidate-nuclide short list as a compromise of contradictory requirements.***

1.8. ***Final selection of a few proper nuclides.***

Presumably divisions **1.5** and **1.6** will discover strong contradictions between nuclear properties themselves and between nuclear and atomic properties. Thus the final choice of nuclides must be done as result of detail analysis taking into account not only physical arguments but also cost accessibility of nuclide to be chosen.

1.9. ***Evolution of corrected numerical data for preliminary general concept.***

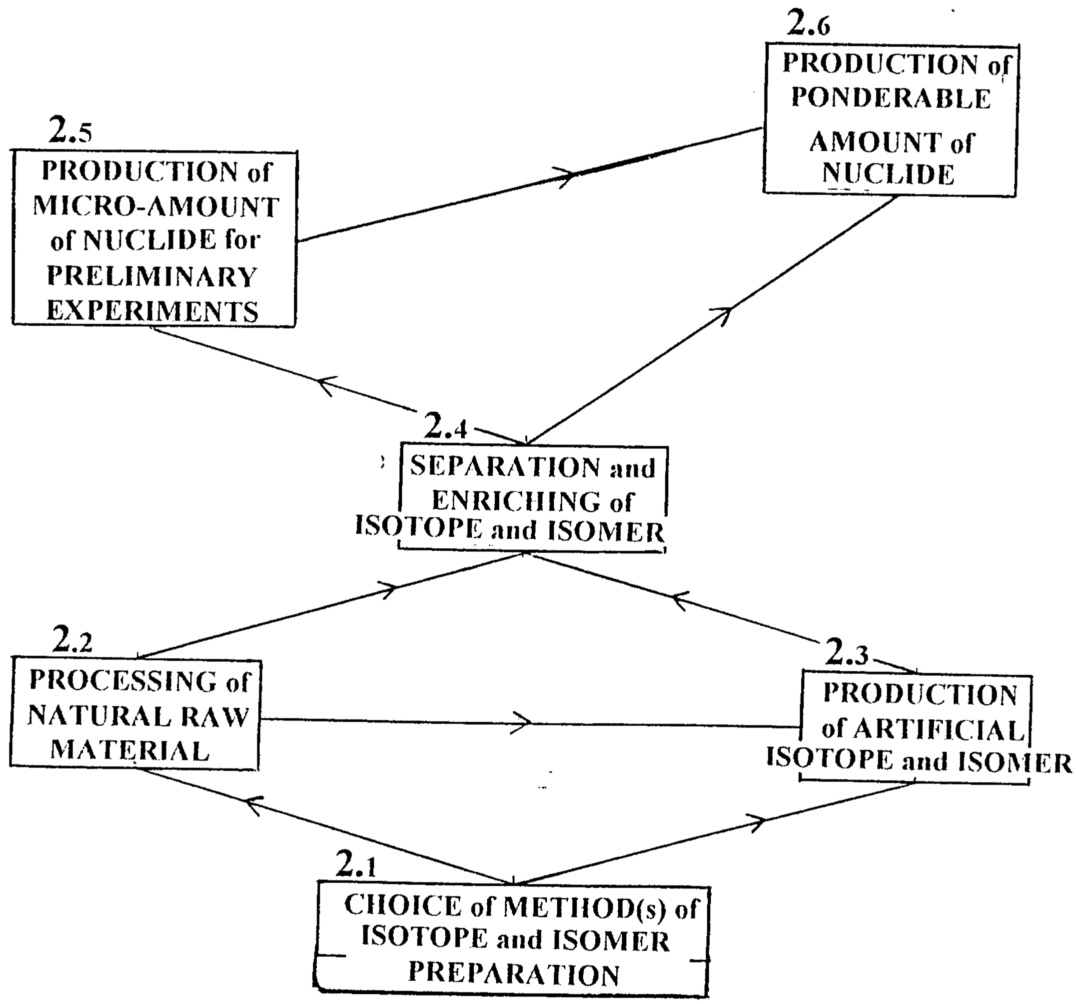
Obtained distinct numerical data for selected nuclide(s) leads to necessity to revise and correct the preliminary quantitative estimates given in the ***Concept*** [1,2] for some hypothetical nuclide and produce a final list parameters of further experiments.

ROAD MAP of R&D

(«Interstate» routs: 2)

NUCLIDE PRODUCTION and SEPARATION

MIREA Tech U



COMMENTS to «INTERSTATE»
ROAD MAP # 2

MIREA
Tech U

GOAL:

To prepare needed quantity of chosen nuclide(s) of sufficient quality.

SOLUTIONS & METHODS:

Standard methods of isotope and isomer production, separation and enriching.

2.1. *Choice of method(s) of isotope and isomer preparation.*

Various known methods of isotope and isomer production (nuclear reactors, particle accelerators, neutron irradiation, chemical treatment, electromagnetic and centrifugal separation, *etc.)* should be considered as an entire complex problem. This task must be solved taking into account not only the technological reasons, but the arguments of total cost too.

2.2. *Processing of natural raw material.*

Necessity of this division is possibly a very infrequent case because of broad spectrum of accessible different nuclides at the market.

2.3. *Production of artificial isotope and isomer.*

2.4. *Separation and enriching of isotope and isomer.*

2.5. *Production of micro-amount of nuclide for preliminary experiments.*

2.6. *Production of ponderable amount of nuclide.*

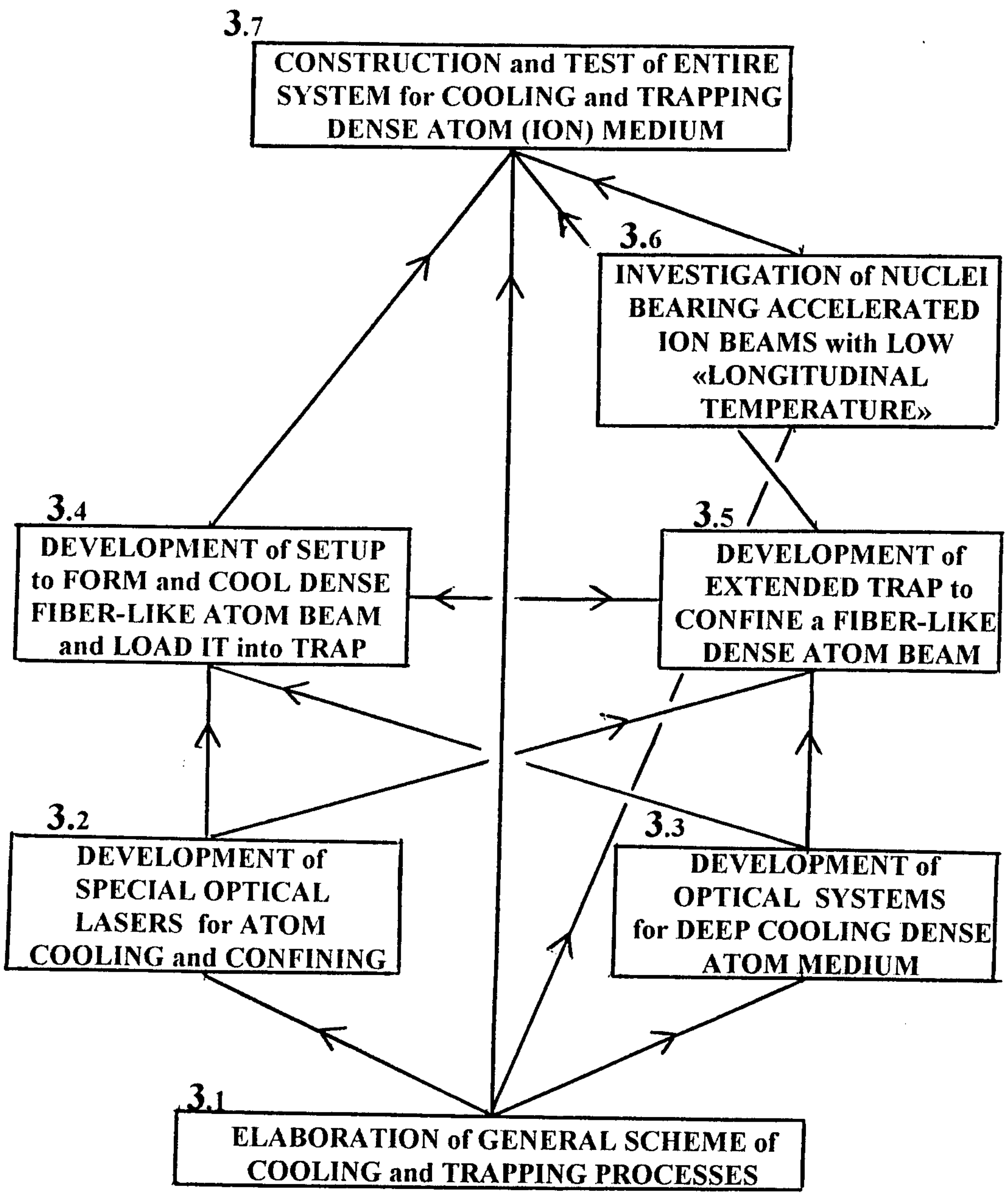
This set of technological procedures must be connected in time into continues chain providing that the total processing time should be much less than the lifetime of isomer metastable state.

ROAD MAP of R&D

(«Interstate» routs: 3)

DEVELOPMENT of ATOM MEDIUM COOLING and TRAPPING

MIREA Tech U



COMMENTS to «INTERSTATE» ROAD MAP # 3

MIREA Tech U

GOAL:

To develop improved system of laser cooling and trapping nuclei bearing fiber-like atom beams with increased concentration and longitudinal extent.

SOLUTIONS & METHODS:

Modern methods of manipulation of neutral atoms by influence of laser light pressure (Doppler- and sub-Doppler cooling, optical and magneto-optical confining, «bottle-neck» loading, etc.).
Improvement of these methods conformably to raised problem (see below).

3.1. ***Elaboration of general scheme of cooling and trapping processes.***

3.7. ***Construction and test of entire system for cooling and trapping dense atom (ion) medium.***

Manifold versions of neutral atom manipulation by laser light pressure [3] and creation of monokinetized ion beams are well known in modern experimental physics. But the present task of creation of nuclei bearing cooled atom (ion) medium is quite different from most usual cases regarding to -

- significantly increased particle density (up to 10^{13}-10^{14} cm^{-3});
- moderately low temperature (of submillikelvin range);
- fiber-like particle beam configuration with extended length and small cross size (for instance, 300 cm over 0.01 cm);
- exclusively stable operation in the vicinity of high power pulsed electric devices.

These features demand some new approaches to elaborate the general scheme of atom medium creation (*e.g*, inclined non-collinear interaction between atom beam and laser light beam of saturating intensity, or coherent interaction of atom ensemble with a set of ultrashort laser π-pulses - for instance, see [4]).

The final test of entire system can be accomplished without need of «hot» laboratory because all these experiments use nuclides in non-radioactive ground or longlived metastable states.

3.2. ***Development of special optical lasers for atom cooling and confining.***

3.4. ***Development of setup to form and cool dense fiber-like atom beam and load it into trap.***

According to remarks of previous division the special optical lasers should be developed which must be able to operate in mentioned new regimes possessing simultaneously band like or (if needed) tubular output beams. Of course, operating power and wavelength should be adequate to needed atom resonances.

3.3. ***Development of optical systems for deep cooling dense atom medium.***

Optical system for distribution of all light signals should consist the stabilizing devices, perhaps, with optical feedbacks.

3.5. ***Development of extended trap to confine a fiber-like dense atom beam.***

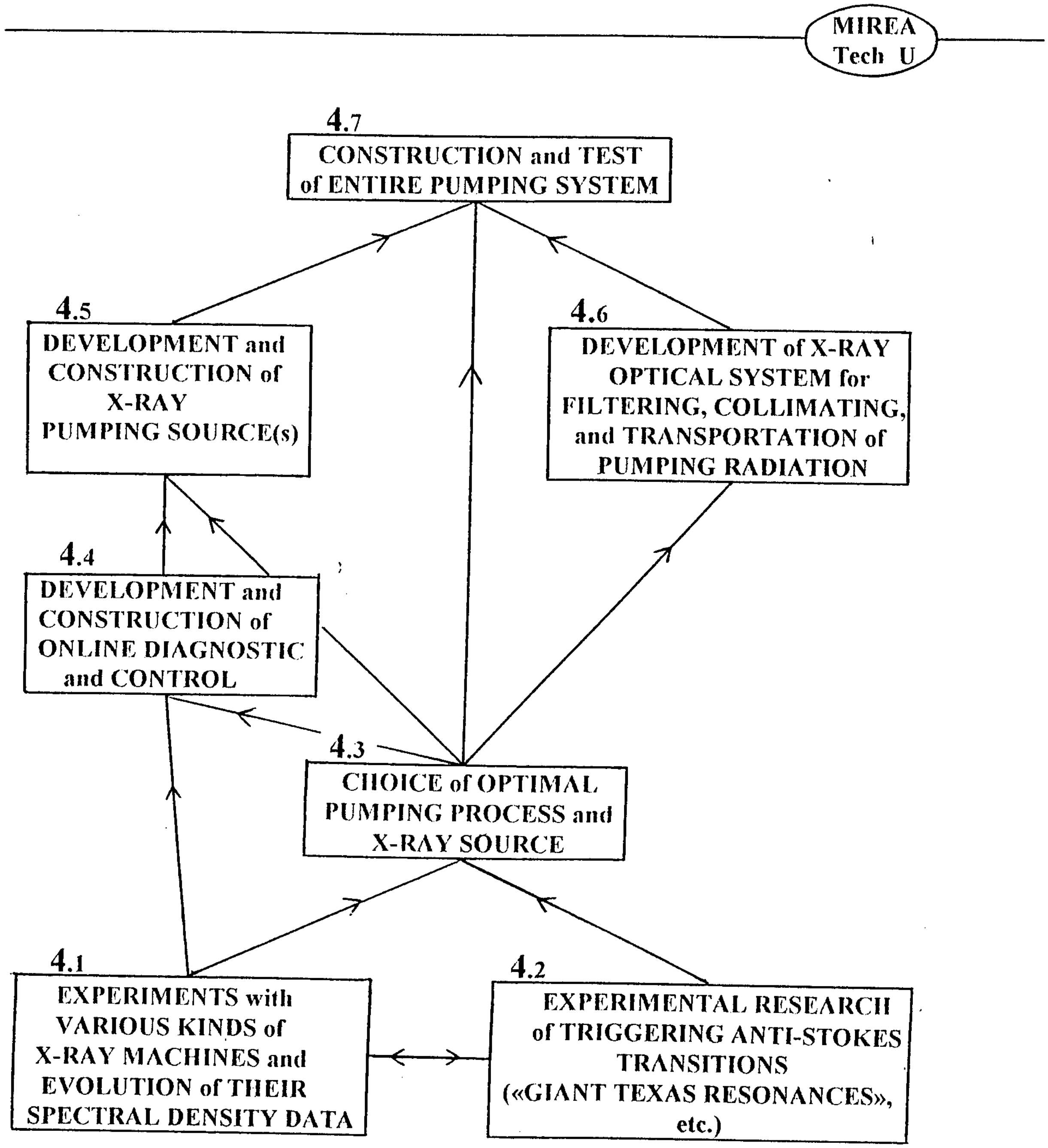
Optical or magneto-optical trap [3] had to be deep and long enough to confine dense and extended atom beam (~300 cm). Today there is no experience in constructing such traps.

3.6. ***Investigation of nuclei bearing accelerated ion beams with low «longitudinal temperature».*** Electrical acceleration of ion beam decreases the longitudinal velocity spread owing to non-linear dependence of ion energy on velocity. Acceleration up to hundreds of keV may lead to effective «longitudinal temperature» of microKelvin range. Currently it is not clear is it possible to extend this pure kinematic methods on dense ion beams, where different plasma effects take place.

ROAD MAP of R&D

(«Interstate» routs: 4*)*

DEVELOPMENT of PUMPING PROCESS and X-RAY SOURCES



COMMENTS to «INTERSTATE» ROAD MAP # 4

MIREA Tech U

GOAL:

To develop efficient X-ray pumping system based on existing X-ray machines.

SOLUTIONS & METHODS:

Comparative investigations of various kinds of X-ray sources (Z-pinch liner machines; X-ray plasma lasers; Synchrotrons; FELs and wigglers; Relativistic Compton scatter machines; Dense plasma generated by terawatt optical lasers; etc.) and eventual improvement of their output properties.

Experimental investigation of excitation cross-sections of chosen nuclides under low intensity X-ray irradiation.

4.1. *Experiments with various kinds of X-ray machines and evolution of their spectral density data.*

4.3. *Choice of optimal pumping process and X-ray source.*

4.4. *Development and construction of online diagnostic and control.*

4.5. *Development and construction of X-ray pumping source(s).*

A lot of efficient X-ray sources of high intensity are known in modern practice (X-ray plasma lasers, synchrotrons, wigglers, Compton scatter sources, free electron lasers, Z-pinch liners with exploding wires, dense plasma emission of terawatt optical lasers, etc.), but the necessity in exhaustive detail information on different combinations of spectral density, divergence and time duration is obvious. Thus a set of comparative measurements must be accomplished to compile the data needed for correct choice of optimal X-ray source and technical specifications for improvement and upgrade of its parameters.

The preliminary estimates of desired parameters are [1,2]:

- photon energy range — 100 - 5000 eV
- spectral density — $> 10^{14}$ photons $cm^{-2} s^{-1} Hz^{-1}$
- divergence — < 0.01 rad
- pulse duration — $\sim$ 10 - 100 ns

Unfortunately it seems that no one of quoted X-ray sources is currently up to the mark of all these desired parameters simultaneously. So some new approaches are of importance. In this connection a tentative proposal of the feasibility of launching a nuclear chain reaction of anti-Stokes radiative transitions in longlived metastable isomers accompanying by intense X-ray burst emission [11] may be of interest.

4.2. ***Experimental research of triggering anti-Stokes transitions («Giant Texas Resonances», etc.)***

These experiments are aimed at the measurements of cross-sections of «two-level» and anti-Stokes transitions in certain chosen nuclides, especially in nuclei with so called «Giant Texas Resonances» [5,6]. Low intensity X-ray sources may be used for these measurements.

4.6. ***Development of X-ray optical system for filtering, collimating, and transportation of pumping radiation.***

Unfortunately, most above mentioned X-ray sources possess very broad beam divergence and even 4π isotropic emission with almost continuous spectrum. So the necessity arises to filter and collimate the output radiation. Moreover there is a necessity to transport this radiation to nuclear medium from remote high power X-ray machine. Presumably X-ray optics systems using some kinds of fibers or capillaries [7,8] may help in solving these tasks. Applicability for these purposes of so called focusing multimode waveguides [9,10] in the X-ray range is also of interest.

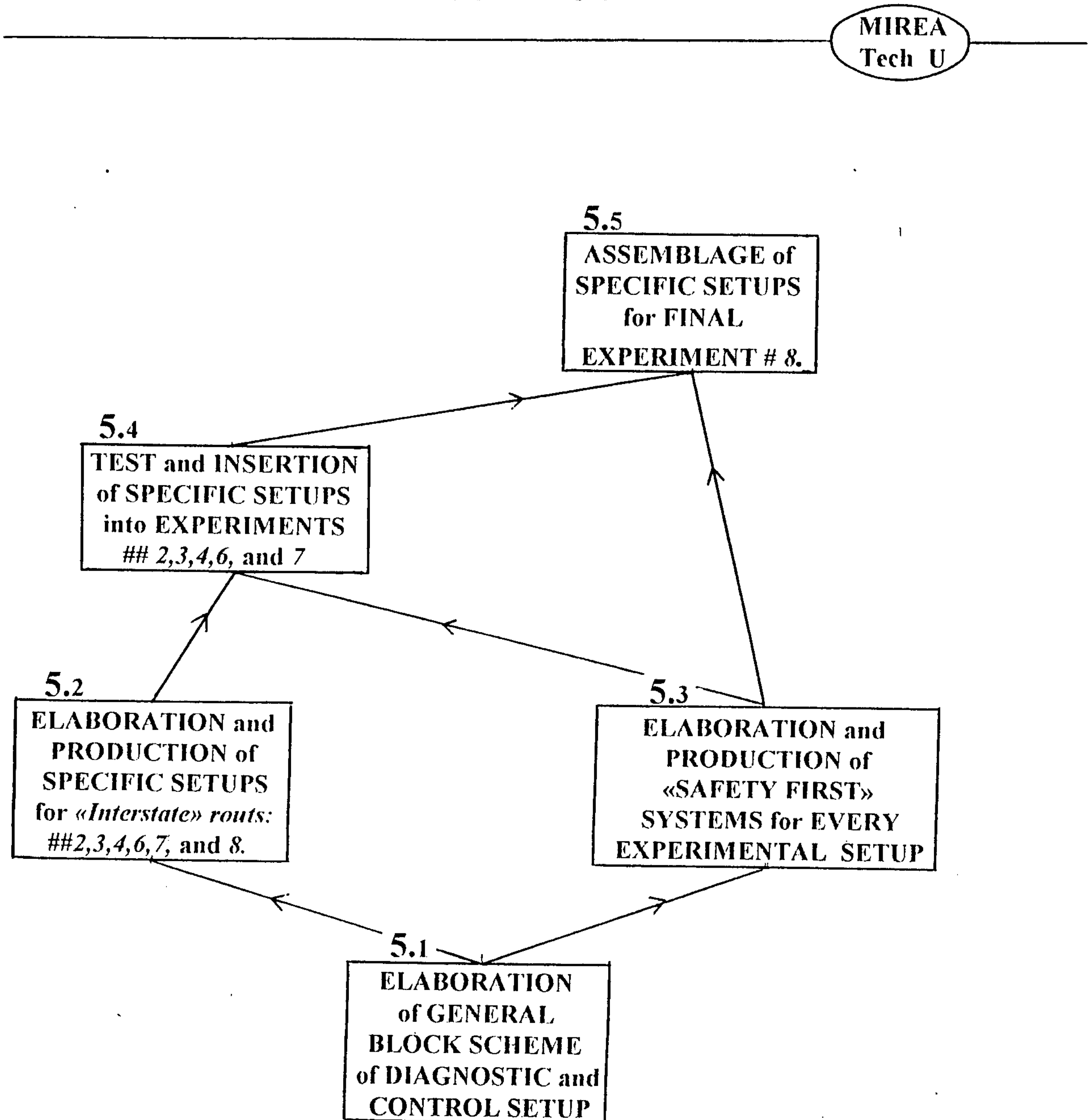
4.7. ***Construction and test of entire pumping system.***

The test of entire pumping system must confirm its stable operation with all needed output parameters (see Comments to **4.1**, **4.3** - **4.5**) and the ability to be synchronized with another setups.

ROAD MAP of R&D

(«Interstate routs: 5)

DEVELOPMENT of ONLINE DIAGNOSTIC and CONTROL



COMMENTS to «INTERSTATE»
ROAD MAP # 5

MIREA
Tech U

GOAL:

To provide permanent automatic online diagnostic and control service for very complicated and diverse experimental system.

SOLUTIONS & METHODS:

Development of new measurement devices and application of known contemporary methods of computer control.

5.1. ***Elaboration of general block scheme of diagnostic and control setup.***

5.2. ***Elaboration and production of specific setups for «interstate» routs ## 2,3,4,6, and 8.***

5.3. ***Elaboration and production of «safety first» system for every experimental setup.***

5.4. ***Test and insertion of specific setups into experiments ## 2,3,4,6, and 7.***

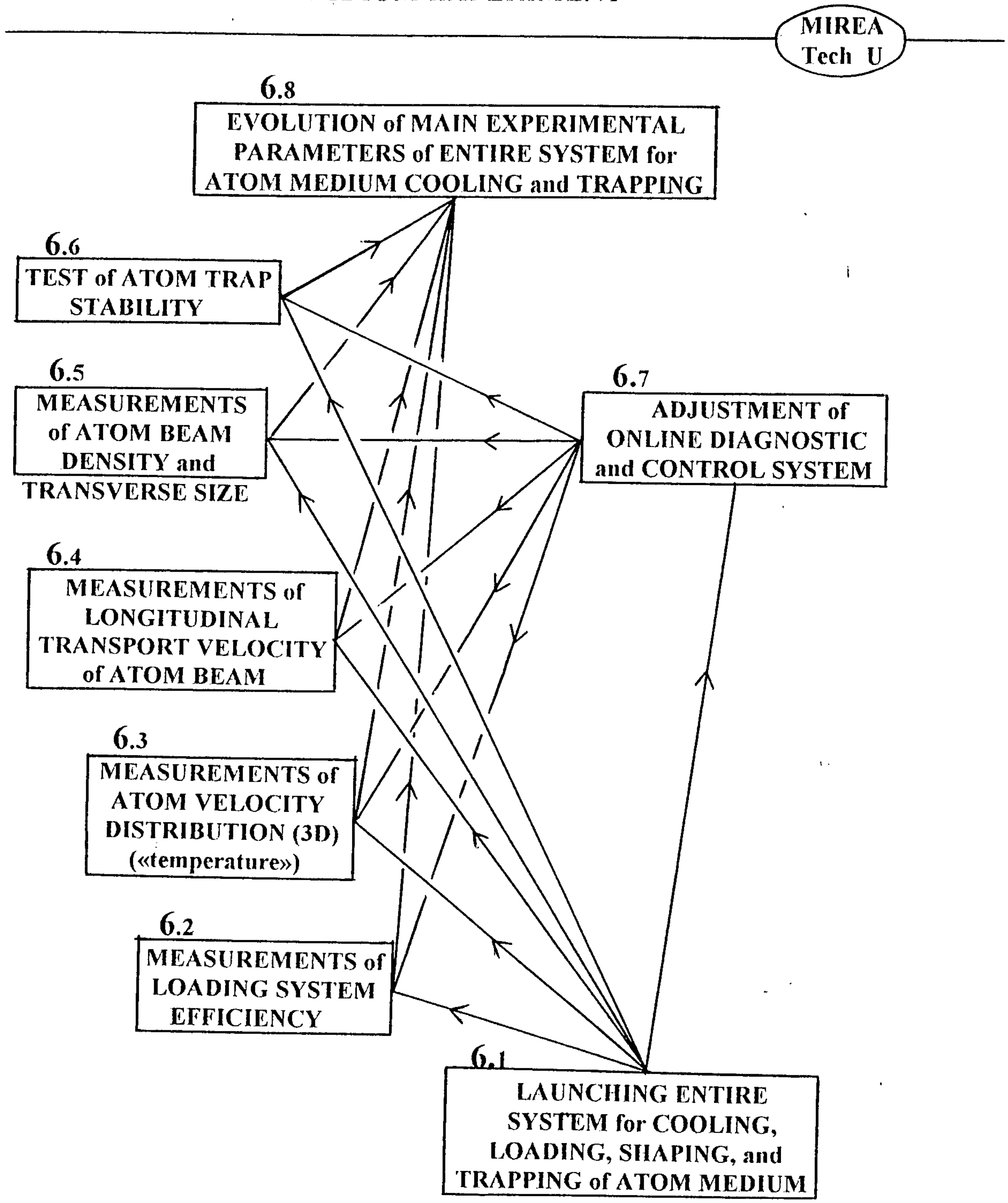
5.5. ***Assemblage of specific setups for final experiment # 8.***

Complexity of separate devices and the entire experimental setup demands to use an automatic online diagnostic and control service system including «safety first» devices (both against electric and X-ray and radioactivity danger).

ROAD MAP of R&D

(Interstate» routs: 6)

NON-RADIOACTIVE COOLED ATOM MEDIUM EXPERIMENT



COMMENTS to «INTERSTATE»
ROAD MAP # 6

MIREA
Tech U

GOAL:

To prove operation of entire combined system for creating nuclei bearing atom medium based on all technologies of neutral atom manipulation by optical lasers developed in a frame of «interstate» road map # 3.

SOLUTIONS & METHODS:

- *Measurements of main atom medium parameters using non-radioactive nuclides*

6.1. ***Launching entire system for cooling, shaping, and trapping of atom medium.***

This experiment shall not demand a «hot» laboratory because it can be accomplished with ponderable amount of nuclei but being in non-radioactive ground or longlived metastable states. A set of special non-invasive (non-perturbative) methods of measurements for ## **6.2** - **6.6** should be developed.

6.2. ***Measurements of loading system efficiency.***

Efficiency of developed source of nuclei bearing atoms should be high enough to provide a loading of cooling and confinement devices with a total atom flow rate

$$\textit{approximately } 10^{14} - 10^{15} \textit{ atom } s^{-1}$$

and concentrating the atom stream to the density

$$\textit{approximately } 10^{18} - 10^{19} \textit{ atom } cm^{-2} s^{-1}.$$

6.3. ***Measurements of atom velocity distribution (3D) («temperature»).***

«Longitudinal» atom «temperature» should lie in a submillikelvin range depending on a natural radiative linewidth of lasing transition. «Transverse» atom «temperature» must be sufficiently less than the depth of a transverse trap well of confinement device.

6.4. ***Measurements of longitudinal transport velocity of atom beam.***

This velocity (being of the order 10^4 cm s^{-1}) is strongly connected with the figures of # **6.2**.

6.5. Measurements of atom beam density and transverse size.

6.6. Test of atom trap stability.

6.7. Adjustment of online diagnostic and control system.

Nuclei bearing atom density ($> 10^{13}$ cm^{-3}) should be increased as high as possible.

The transverse atom beam size (of the submillimeter range) is determined by the depth of a trap well and the «transverse» atom «temperature». The sufficient stability of a trap means that a trap well prevents atom leakage along a whole atom beam and provides its high rectilinearity with declination much less than a transverse beam size. All these features should be provided by perfect online diagnostic and control system.

6.8. Evolution of main experimental parameters of entire system for atom medium cooling and trapping.

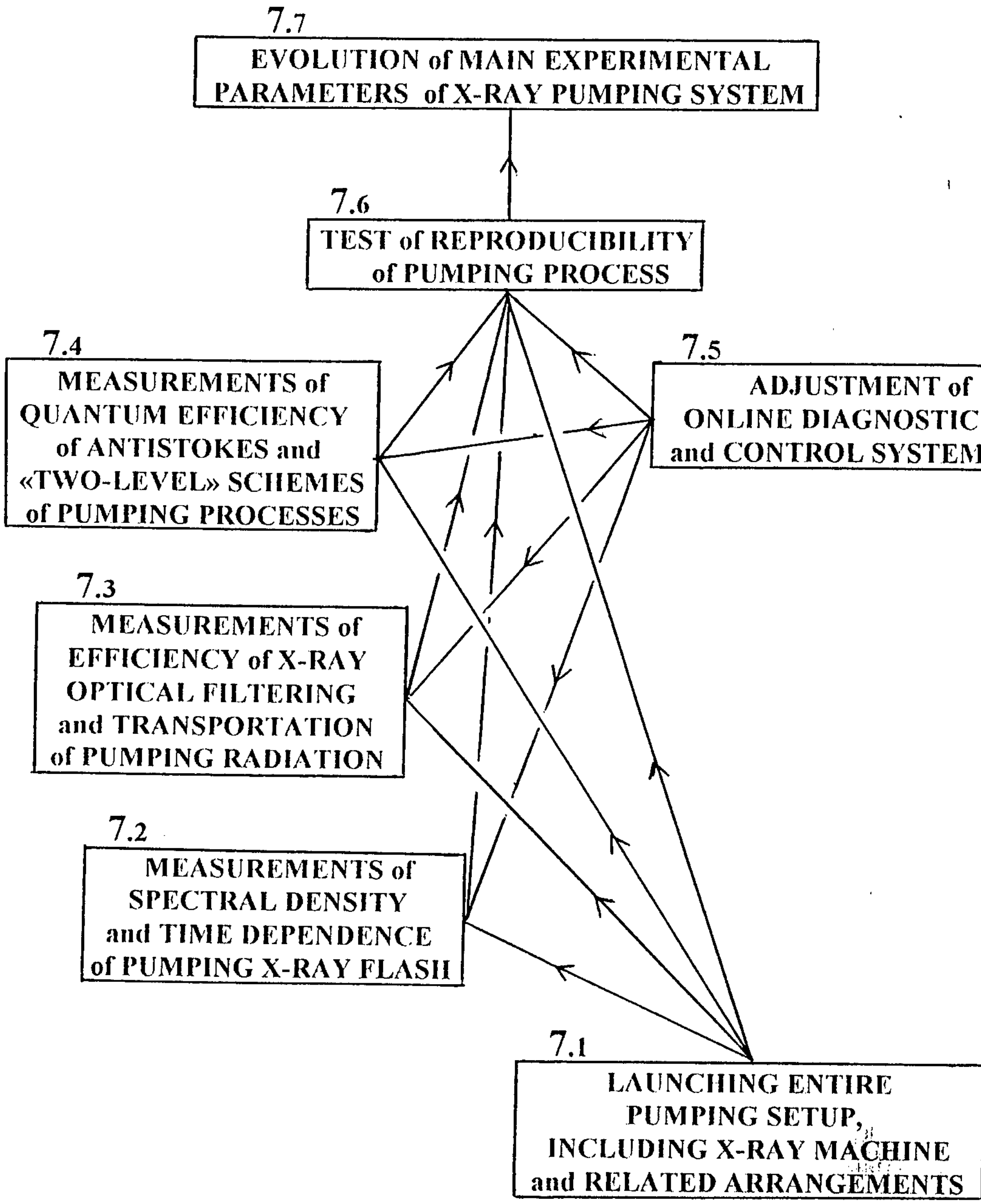
The final test of entire cooling and trapping system - one of the main constituent of the whole GRL setup - shall determine the list of parameters which are most important to elaborate the final construction of the GRL experimental facility.

ROAD MAP of R&D

(«Interstate» routs: 7)

NON-COOLED NUCLEI PUMPING EXPERIMENT

MIREA Tech U



COMMENTS to «INTERSTATE» ROAD MAP # 7

MIREA Tech U

GOAL:

To test operation efficiency of entire X-ray pumping system

SOLUTIONS & METHODS:

Improved standard methods of nuclear gamma-spectroscopy and X-ray optics.

7.1. *Launching entire pumping setup including X-ray machine and related arrangements.*

This division is a strict continuation of # **4.** The X-ray source should be rather one of already existing machines (because of high cost of such facilities) with some necessary improvements and arrangements first of all regarding to increase of photon flow spectral density, decrease of beam divergence, etc.

7.2. *Measurements of spectral density and time dependence of pumping X-ray flash.*

7.3. *Measurements of efficiency of X-ray optical filtering and transportation of pumping radiation.*

These experiments are directed on getting data of these important X-ray pump parameters of completely assembled pumping setup which possibly may differ from that derived in # **4**.

7.4. *Measurements of quantum efficiency of anti-Stokes and «two level» schemes of pumping processes.*

These important measurements should confirm or correct corresponding cross-section data obtained with micro-amount of nuclides under low intensity X-ray irradiation (see **4.2**) for the case of ponderable nuclide amount and completely assembled high intensity pumping setup.

7.5. *Adjustment of online diagnostic and control system.*

7.6. *Test of reproducibility of pumping process.*

Reproducibility of operation of complicated high power machine with corresponding online diagnostic and control service system providing a perfect repetition of main output parameters is an indispensable condition of successful final full scale GRL experiments.

7.7. *Evolution of main experimental parameters of X-ray pumping system.*

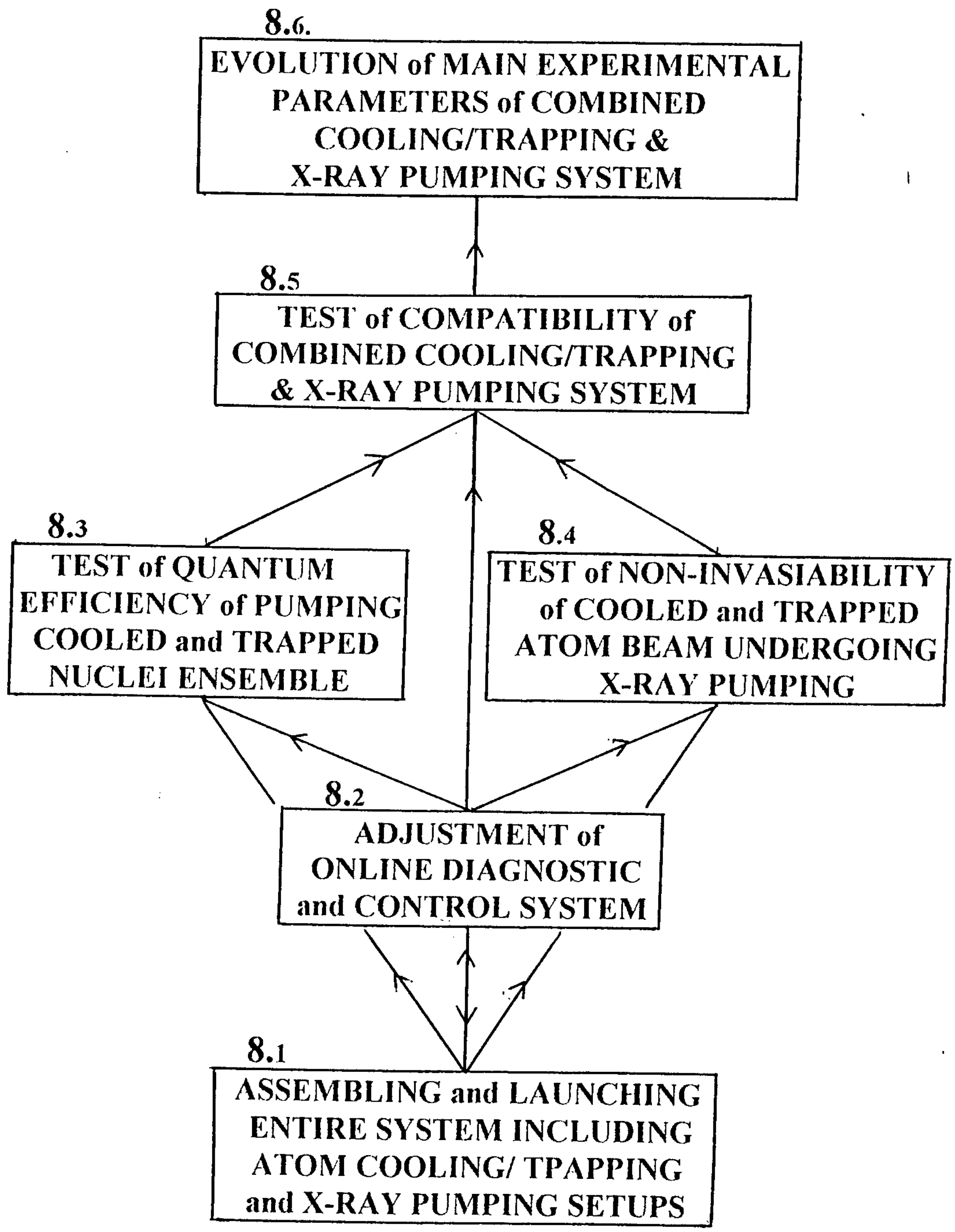
The complete list of main experimental parameters of the entire X-ray pumping system should be used in elaboration of the final construction of the GRL experimental facility.

ROAD MAP of R&D

(«Interstate» routs: 8)

TEST of COOLING and PUMPING PROCESSES COMPATIBILITY

MIREA Tech U



COMMENTS to «INTERSTATE» ROAD MAP # 8

MIREA Tech U

GOAL:

To test operation compatibility of two main experimental systems: optical laser setups to create and maintain cooled and confined nuclei bearing atom medium and devices to pump a nuclear ensemble by X-ray machines.

SOLUTIONS & METHODS:

In fact this test is almost full scale GRL experiment which demands to use all measurement methods developed in previous divisions.

8.1. Assembling and launching entire system including atom cooling/trapping and X-ray pumping setups.

8.2. Adjustment of online diagnostic and control system.

This system is in fact a prototype of a future tentative Full Scale GRL facility. Its operation demands a «hot» laboratory.

8.3. Test of quantum efficiency of pumping cooled and trapped nuclei ensemble.

8.4. Test of non-invasiability of cooled and trapped atom beam undergoing X-ray pumping.

Both tests should confirm the results of # 7.4 on quantum efficiency of anti-Stokes and «two level» pumping processes in nuclei borne by cooled and trapped atom beam and simultaneously demonstrate an unperturbative action of these processes on the atom beam «longitudinal» and «transverse» «temperatures».

8.5. Test of compatibility of combined cooling/trapping and X-ray pumping system.

One may predict some fear upon the compatibility of very delicate device containing deeply cooled atom in a trap with simultaneously operating high power pulsed electric devices for X-ray pump emission. Manifold test of all sides of common operation of combined setup should be performed.

8.6. Evolution of main experimental parameters of combined cooling/trapping and X-ray pumping system.

The complete list of main experimental parameters of combined atom cooling/trapping and X-ray pumping system should be used for the final construction of the GRL facility and detail program of GRL experiments.

ROAD MAP of R&D

(«Interstate» routs: 9)

ELABORATION of PROJECT of FULL SCALE GAMMA-RAY LASING EXPERIMENT

MIREA Tech U

9.4

STATEMENT of EXPECTED MAIN RESULTS and PROSPECTS of FULL SCALE GRL EXPERIMENT

↑

9.3

ELABORATION of TIME and FUNDING SCHEDULES of PHASE II PROJECT

↑

9.2

ELABORATION of COMPLETE TECHNICAL PROJECT of FULL SCALE EXPERIMENT FACILITY with DETAIL DESCRIPTIONS and SPECIFICATIONS of MAIN CONSTITUENTS

↑

9.1

ELABORATION of DETAIL FULL SCALE EXPERIMENT PROGRAM

COMMENTS to «INTERSTATE» ROAD MAP # 9

MIREA Tech U

GOAL:

To prepare the final technical document - the Phase II Project of Full Scale GRL Experiment

SOLUTIONS & METHODS:

Analytical summarizing all results of previous divisions and compiling a completed and exhaustive technical description with detail quantitative specification.

9.1. *Elaboration of detail full scale experiment program.*

9.2. *Elaboration of complete technical project of Full Scale Experiment Facility with detail descriptions and specifications of main constituents.*

This final technical document - the detail Program and Construction Project of Phase II GRL Experiment - should be based on a whole experience of Phase I activity including all lists of experimental data, technical specifications, all discovered «know how», «safety first» system description, and description of special online detection system of GRL output parameters, namely:

- output gamma-photon beam intensity;
- gamma-photon energy (wavelength);
- gamma-ray spectrum;
- gamma-ray line width (degree of coherence);
- gamma-photon beam divergence;
- time dependence of coherent gamma-emission; *etc.*

9.3. *Elaboration of time and funding schedule of Phase II Project.*

9.4. *Statement of expected main results and prospects of Full Scale GRL Experiment.*

Expected main results and scientific and technological prospects of Full Scale GRL Experiment should be stated absolutely clear and legible and grounded on the entire experimental information which would be got during accomplishment of the Phase I Project. These results and prospects should justify all eventual future efforts, time and money expenditures.

«State» Road Maps

ROAD MAP of R&D

(«State» routs: 3.1)

ELABORATION of GENERAL SCHEME of COOLING and TRAPPING PROCESSES

MIREA Tech U

3.1.3
COMPILATION of TECHNICAL SPECIFICATIONS for «STATE» ROUTS ## 3.2 - 3.6

↑

3.1.2
QUANTITATIVE INVESTIGATION (INCLUDING COMPUTER SIMULATION) of PROPOSED SCHEMES for CERTAIN ATOMS CHOSEN in «INTERSTATE» ROAD MAP # 1

↑

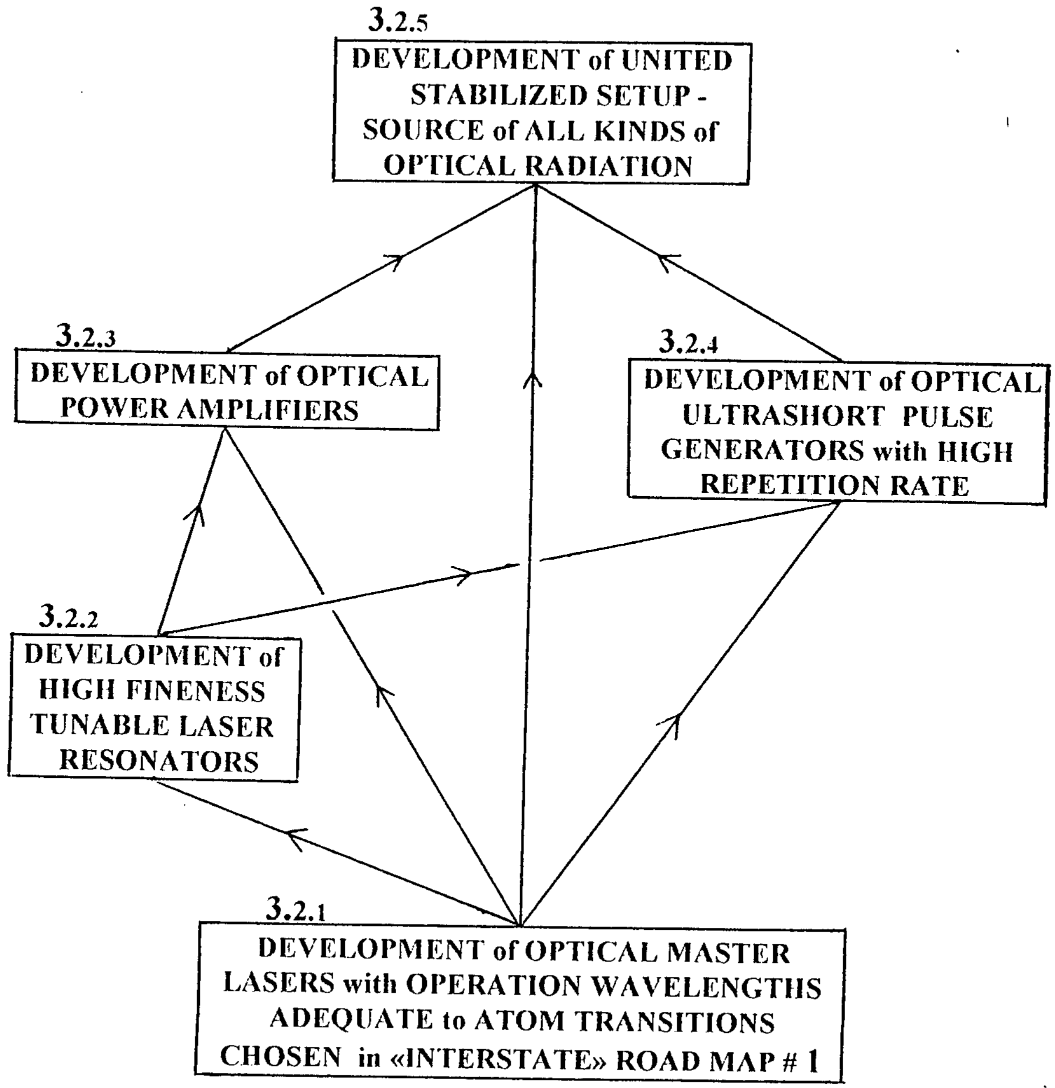
3.1.1
PROPOSALS of NEW IMPROVED SCHEMES of ATOM MANIPULATION by LASER LIGHT for SIGNIFICANT INCREASE of DENSITY and EXTENSION of NUCLEAR MEDIUM

ROAD MAP of R&D

(«State» routs: 3.2)

DEVELOPMENT of SPECIAL OPTICAL LASERS for ATOM COOLING and CONFINING

MIREA Tech U

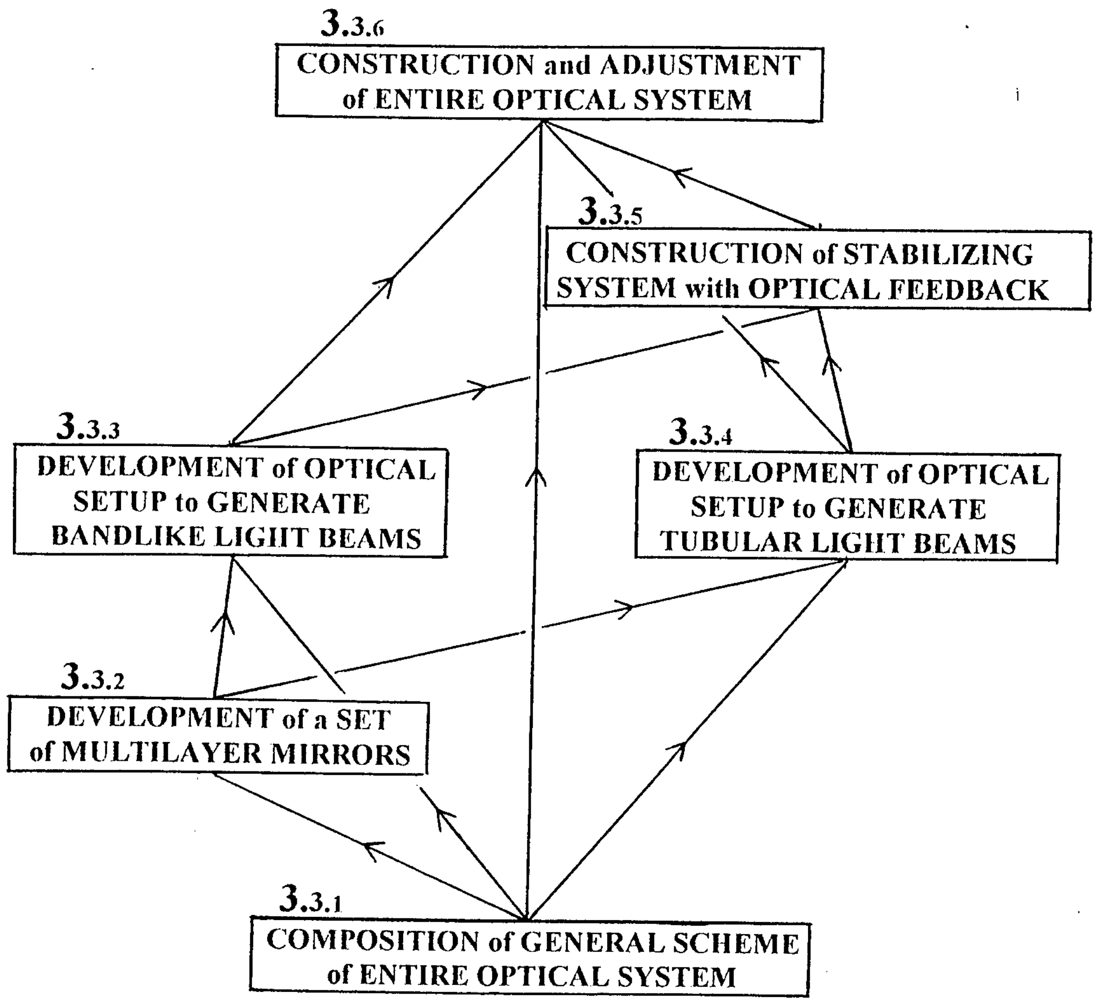


ROAD MAP of R&D

(«State» routs: 3.3)

DEVELOPMENT of OPTICAL SYSTEMS
for DEEP COOLING DENSE ATOM MEDIUM

MIREA
Tech U



ROAD MAP of R&D

(«State» routs: 3.4)

DEVELOPMENT of SETUP to FORM and COOL DENSE FIBER-LIKE ATOM BEAM and LOAD IT into TRAP

MIREA Tech U

3.4.3

TEST of ENTIRE SETUP and COMPILATION of TECHNICAL DESCRIPTION and SPECIFICATIONS

↑

3.4.2

PRODUCTION of ENTIRE SETUP INCLUDING ATOM SOURCE and COOLING/FORMING/LOADING DEVICES

↑

3.4.1

ELABORATION of ATOM SOURCE with HIGH OUTPUT FLOW and COOLING/FORMING/LOADING DEVICES ACCORDING to «STATE» ROAD MAP # 3.1

ROAD MAP of R&D

(«State» routs: 3.5)

DEVELOPMENT of EXTENDED TRAP to CONFINE a FIBER-LIKE DENSE ATOM BEAM

MIREA Tech U

3.5.3

TEST of ENTIRE CONFINEMENT SETUP and COMPILATION of TECHNICAL DESCRIPTION and SPECIFICATIONS

3.5.2

PRODUCTION of TPAP DEVICE

3.5.1

ELABORATION of EXTENDED TRAP for HIGH DENSITY COOLED ATOM BEAM ACCORDING to «STATE» ROAD MAP # 3.1

ROAD MAP of R&D

(«State» routs: 3.6)

CONSTRUCTION and TEST of ENTIRE SYSTEM for COOLING and TRAPPING DENSE ATOM MEDIUM

MIREA Tech U

3.6.3

COMPILATION of DETAIL TECHNICAL DESCRIPTION and SPECIFICATIONS

↑

3.6.2

TEST of ENTIRE SYSTEM

↑

3.6.1

ASSEMBLING and LAUNCHING ENTIRE SYSTEM for ATOM BEAM COOLING/LOADING/CONFINING

ROAD MAP of R&D

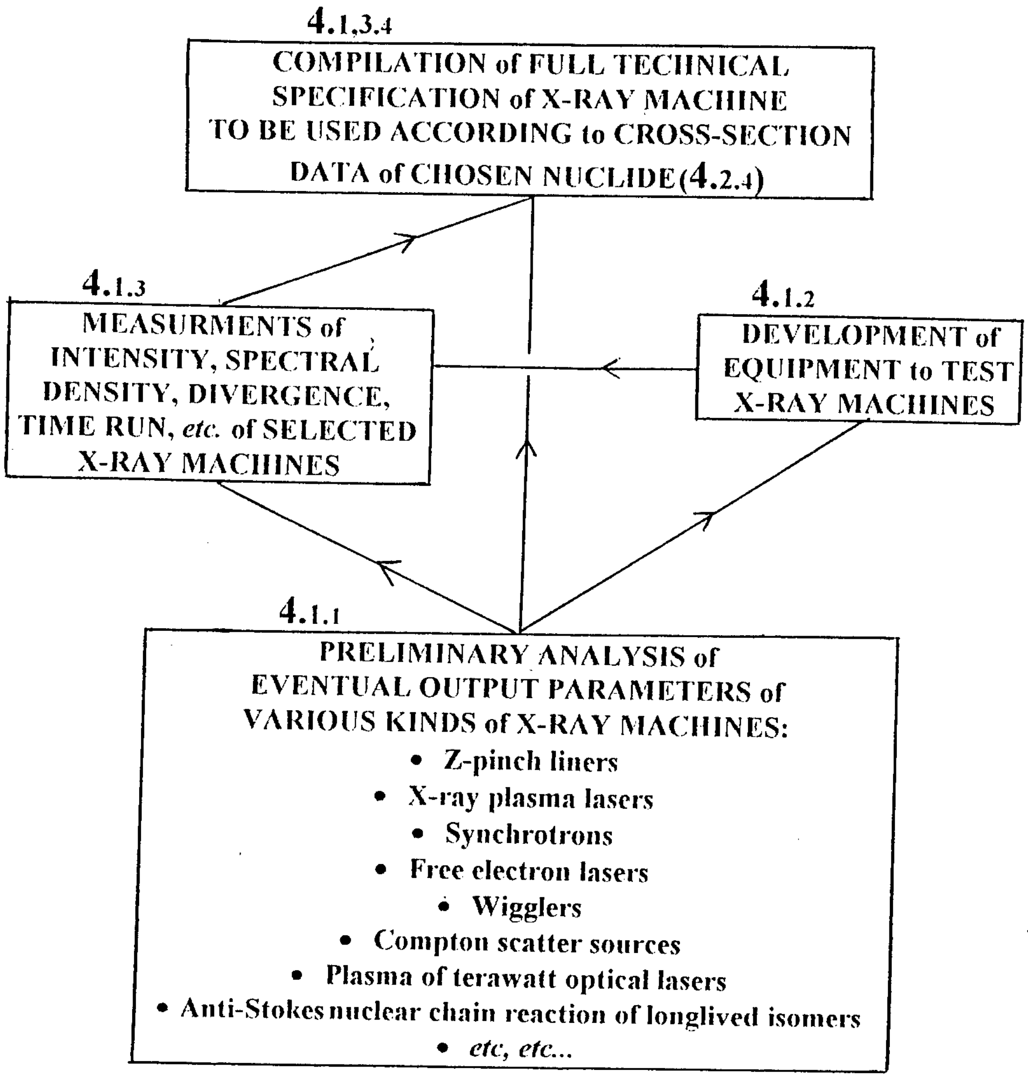
(«State» routs: 4.1,3*)*

EXPERIMENTS with VARIOUS KINDS of X-RAY MACHINES and EVOLUTION of THEIR SPECTRAL DENSITY DATA

&

CHOICE of OPTIMAL PUMPING PROCESS and X-RAY SOURCE

MIREA Tech U

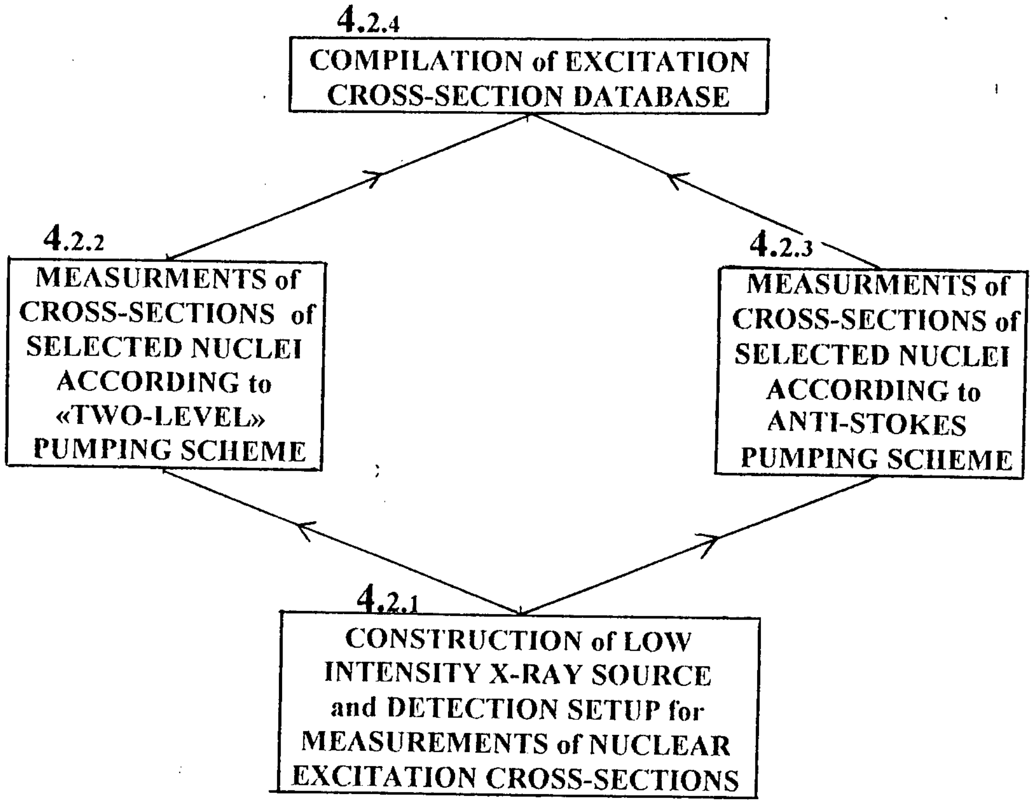


ROAD MAP of R&D

(«State» routs: 4.2)

EXPERIMENTAL RESEARCH of TRIGGERINGANTI-STOKES TRANSITIONS, etc

MIREA Tech U

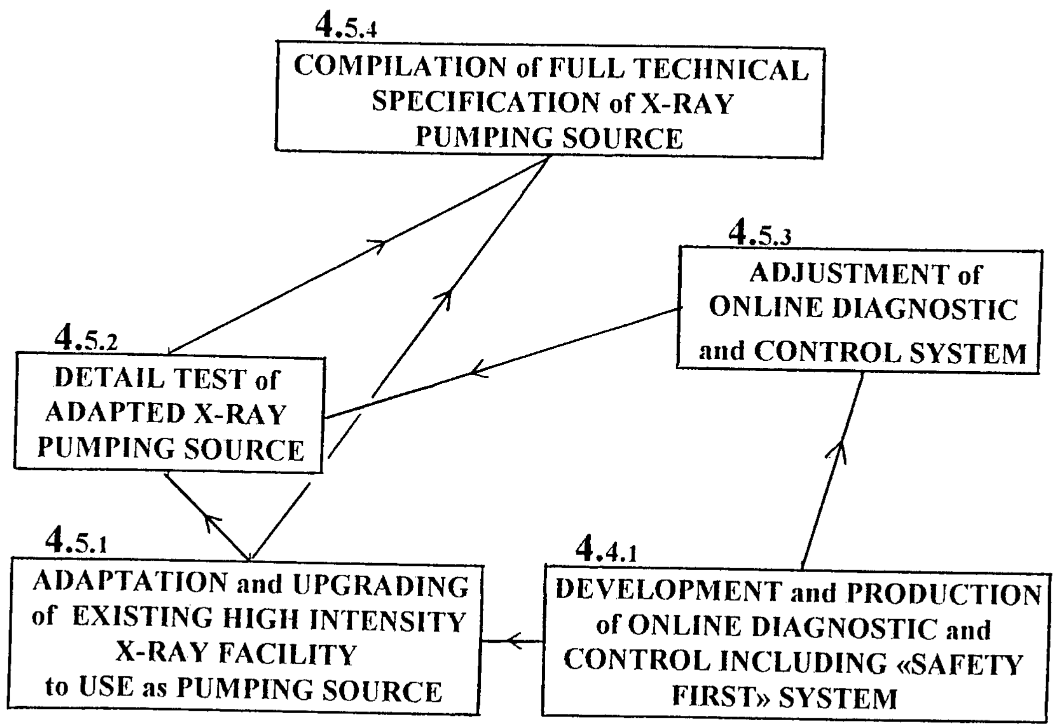


ROAD MAP of R&D

(«State» routs: 4.4,5)

DEVELOPMENT and CONSTRUCTION of ONLINE DIAGNOSTIC and CONTROL & DEVELOPMENT and CONSTRUCTION of X-RAY PUMPING SOURCE(s)

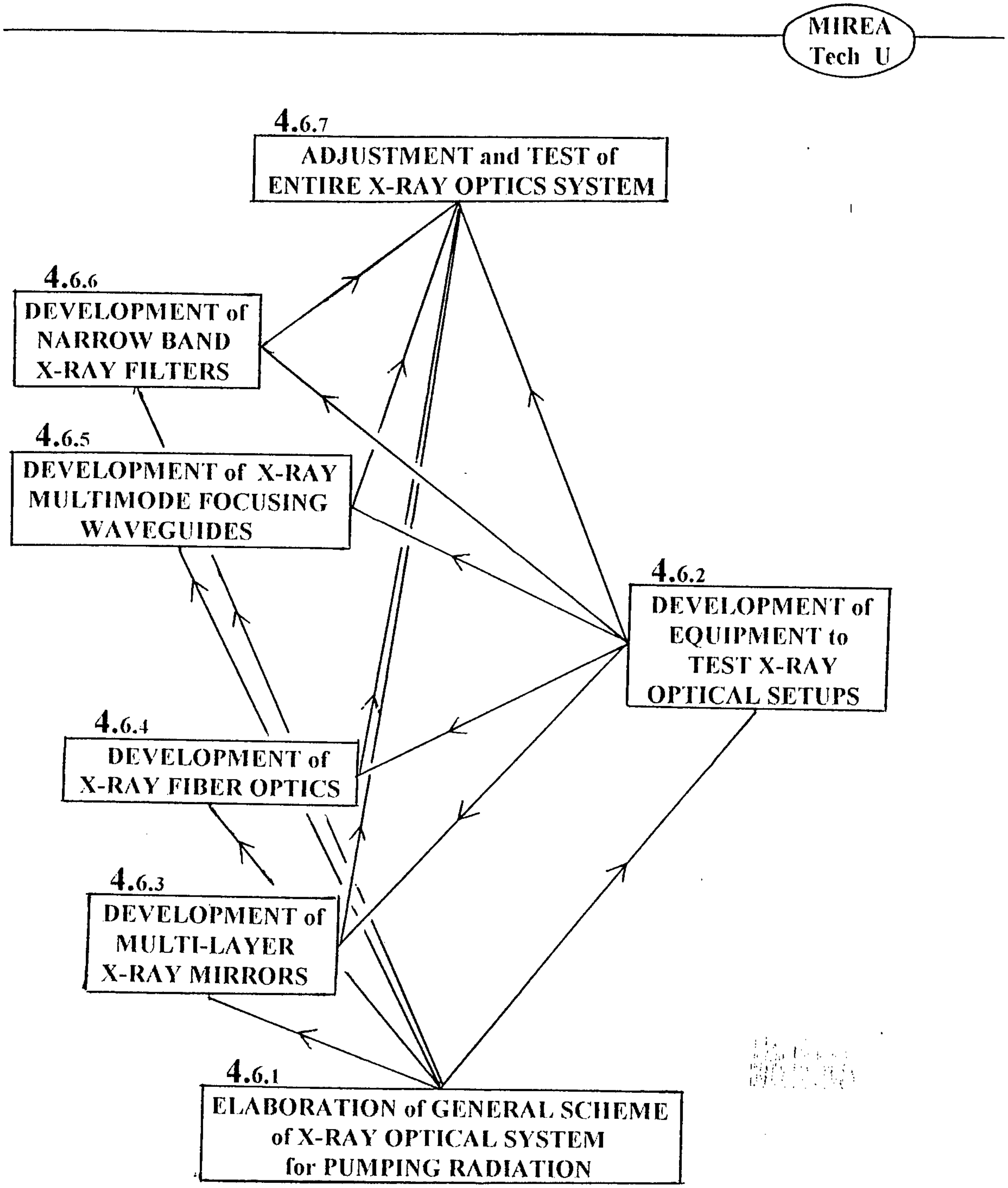
MIREA Tech U



ROAD MAP of R&D

(«State» routs: 4.6)

DEVELOPMENT of X-RAY OPTICAL SYSTEM for FILTERING, COLLIMATING and TRANSPORTATION of PUMPING RADIATION



ROAD MAP of R&D

(«State» routs: 4.7)

CONSTRUCTION and TEST of ENTIRE PUMPING SYSTEM

MIREA Tech U

4.7.2

TEST and COMPILATION of TECHNICAL DESCRIPTION and SPECIFICATIONS of X-RAY PUMPING FACILITY

↑

4.7.1

ASSEMBLAGE and ADJUSTMENT of ENTIRE PUMPING FACILITY INCLUDING X-RAY OPTICAL SYSTEM, ONLINE DIAGNOSTIC and CONTROL, and «SAFETY FIRST» DEVICES

ROAD MAP of R&D

(«State» routs: 6.1,7)

LAUNCHING ENTIRE SYSTEM for COOLING, LOADING, and TRAPPING of ATOM MEDIUM

&

ADJUSTMENT of ONLINE DIAGNOSTIC and CONTROL SYSTEM

MIREA
Tech U

6.1,7.2

TEST and GENERAL DESCRIPTION of UNITED SYSTEM

↑

6.1,7.1

ASSEMBLAGE of UNITED COOLING/LOADING/TRAPPING SETUPS (# 3) and ONLINE DIAGNOSTIC and CONTROL SYSTEM

ROAD MAP of R&D

(«State» routs: 6.2 -6,8)

**MEASUREMENTS of LOADING SYSTEM EFFICIENCY,
MEASUREMENTS of ATOM VELOCITY DISTRIBUTION
(3D) («temperature»),
MEASUREMENTS of LONGITUDINAL TRANSPORT
VELOCITY of ATOM BEAM,
MEASUREMENTS of ATOM BEAM DENSITY
and TRANSVERSE SIZE,
TEST of ATOM TRAP STABILITY,
&
EVOLUTION of MAIN EXPERIMENTAL PARAMETERS
of ENTIRE SYSTEM for ATOM MEDIUM
COOLING and TRAPPING**

MIREA Tech U

6.8.4

COMPILATION of LIST of PARAMETERS and TECHNICAL SPECIFICATIONS of ENTIRE SYSTEM for ATOM COOLING and TRAPPING

↑

6.2-6.3

ACCOMPLISHMENT of ENTIRE SET of MEASUREMENTS

↑

6.2-6.2

ELABORATION and PRODUCTION of a SET of MEASUREMENT DEVICES

↑

6.2-6.1

ELABORATION of MEASUREMENT PROGRAM for ## 6.2 - 6.6

ROAD MAP of R&D

(«State» routs: 7.1,5,6)

LAUNCHING ENTIRE PUMPING SETUP INCLUDING X-RAY MACHINE and RELATED ARRANGEMETS, ADJUSTMENT of ONLINE DIAGNOSTIC and CONTROL SYSTEM,

&

TEST of REPRODUCIBILITY of PUMPING PROCESS

MIREA Tech U

7.1,5,6.2

TEST of RELIABILITY of UNITED PUMPING FACILITY and REPRODUCIBILITY of ANTI-STOKES and «TWO-LEVEL» EXCITATION PROCESSES

↑

7.1,5,6.1

LAUNCHING of UNITED FACILITY INCLUDING X-RAY MACHINE, A SET of MEASUREMENT DEVICES, ONLINE DIAGNOSTIC and CONTROL SETUP, and «SAFETY FIRST» SYSTEM

ROAD MAP of R&D

(«State» routs: 7.2-4,7)

MEASUREMENTS of SPECTRAL DENSITY and TIME DEPENDENCE of PUMPING X-RAY FLASH, MEASUREMENTS of EFFICIENCY of X-RAY OPTICAL FILTERING and TRANSPORTATION of PUMPING RADIATION, MEASUREMENTS of QUANTUM EFFICIENCY of ANTI-STOKESand «TWO-LEVEL» SCHEMES of PUMPING PROCESSES, & EVOLUTION of MAIN EXPERIMENTAL PARAMETERS of X-RAY PUMPING SYSTEM

MIREA Tech U

7.2-4,7.4

COMPILATION of LIST of EXPERIMENTAL PARAMETERS and TECHNICAL SPECIFICATIONS of X-RAY PUMPING FACILITY

↑

7.2-4,7.3

ACCOMPLISHMENT of a SET of DETAIL MEASUREMENTS USING PONDERABLE AMOUNT of NON-COOLED NUCLEI

↑

7.2-4,7.2

DEVELOPMENT of a SET of MEASURING DEVICES

↑

7.2-4,7.1

DEVELOPMENT of PROGRAM of MEASUREMENTS

ROAD MAP of R&D

(«State» routs: 8.1,2)

ASSEMBLING and LAUNCHING ENTIRE SYSTEM INCLUDING ATOM COOLING/TRAPPING and X-RAY PUMPING SETUPS

&

ADJUSTMENT of ONLINE DIAGNOSTIC and CONTROL SYSTEM

MIREA Tech U

8.1,2.2

LAUNCHING and OPERATION TEST of COMBINED FACILITY

8.1,2.1

ASSEMBLAGE of COMBINED FACILITY CONSISTING of ATOM COOLING/TRAPPING SYSTEM, REMUTE X-RAY PUMPING MACHINE, X-RAY OPTICAL SYSTEM for FILTERING/COLLIMATING and TRANSPORTATION of PUMPING RADIATION(# 4.6), ONLINE DIAGNOSTIC and CONTROL SYSTEM, and «SAFETY FIRST» SETUPS

ROAD MAP of R&D

(«State» routs: 8.3)

TEST of QUANTUM EFFICIENCY of PUMPING COOLED and TRAPPED NUCLEI ENSEMBLE

MIREA Tech U

8.3.4

COMPILATION of LIST of TECHNICAL SPECIFICATIONS

↑

8.3.3

ACCOMPLISHMENT of a SET of MEASUREMENTS ACCORDING to ANTI-STOKES and «TWO-LEVEL» PUMPING SCHEMES

↑

8.3.2

DEVELOPMENT of a SET of MEASURING METHODS and DEVICES

↑

8.3.1

ELABORATION of PROGRAM of MEASUREMENTS of PUMPING EFFICIENCY of COOLED and TRAPPED NUCLEI

ROAD MAP of R&D

(«State» routs: 8.4)

TEST of NON-INVASIABILITY of COOLED and TRAPPED ATOM BEAM UNDERGOING X-RAY PUMPING

MIREA
Tech U

8.4.5
COMPILATION of LIST of TECHNICAL SPECIFICATIONS

↑

8.4.4
MEASUREMENT of DISCRETE LONGITUDINAL ATOM VELOCITY DISTRIBUTION MODIFIED by STRONG X-RAY PUMPING

↑

8.4.3
ACCOMPLISHMENT of a SET of MEASUREMENTS ANALOGOUS to ## 6.2-5 but UNDER CIRCUMSTANCES of STRONG X-RAY PUMPING

↑

8.4.2
DEVELOPMENT of a SET of MEASURING METHODS and DEVICES

↑

8.4.1
DEVELOPMENT of PROGRAM of MEASUREMENTS

ROAD MAP of R&D

(«State» routs: 8.5,6)

TEST of COMPATIBILITY of COMBINED COOLING/TRAPPING & X-RAY PUMPING SYSTEM
&
EVOLUTION of MAIN EXPERIMENTAL PARAMETERS of COMBINED COOLING/TRAPPING & X-RAY PUMPING SYSTEM

MIREA Tech U

8.6.3

COMPILATION of TECHNICAL DESCRIPTION and SPECIFICATIONS of COMBINED COOLING/TRAPPING and X-RAY PUMPING SYSTEM

↑

8.5,6.2

CONCLUSION on OPERATION COMPATIBILITY of COMBINED COOLING/TRAPPING and X-RAY PUMPING SYSTEM BASED on POSITIVE RESULTS of ## 8.3, 8.4, and 8.5,6.1

↑

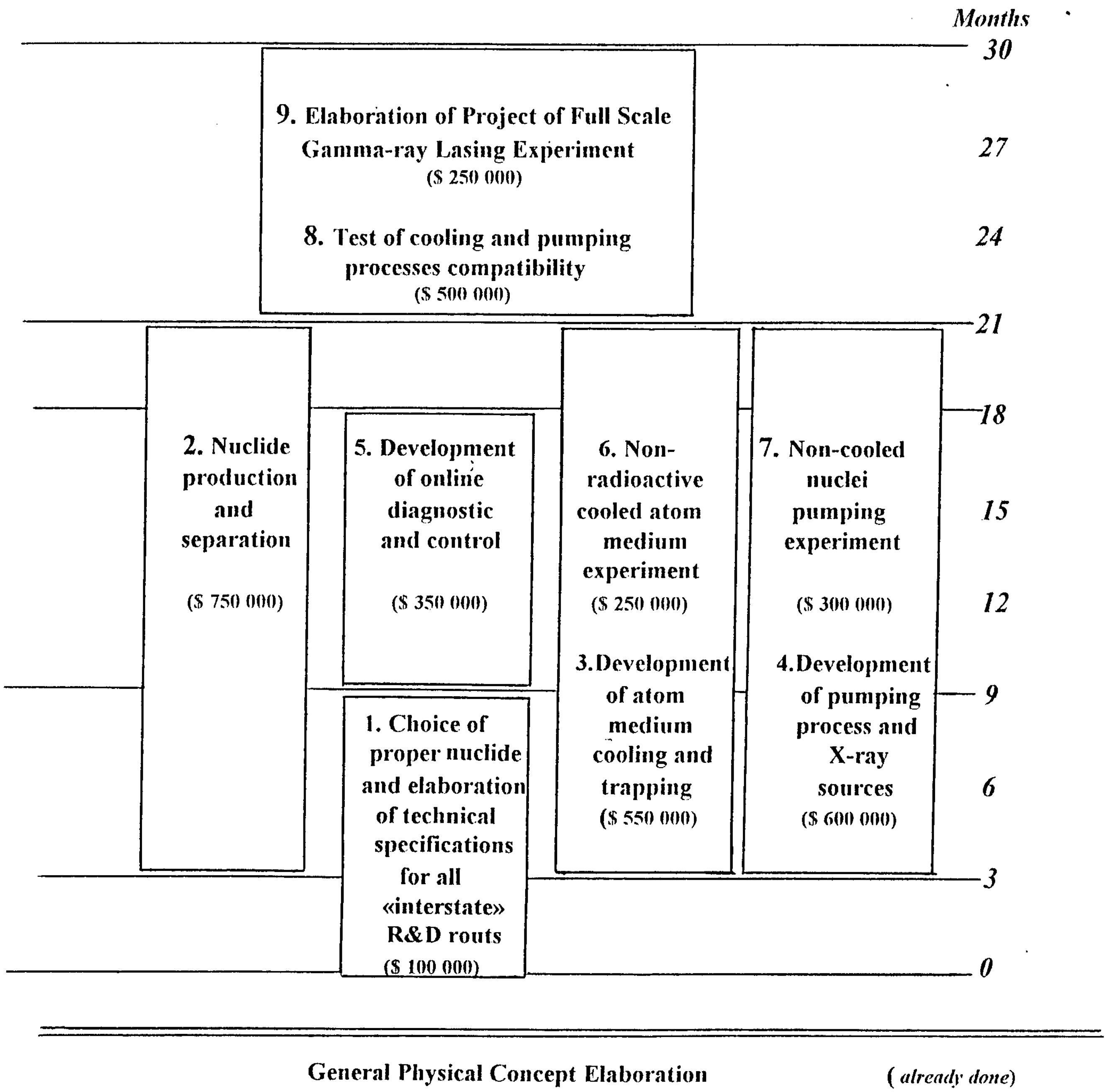
8.5.1

TEST of OPERATION RELIABILITY and REPRODUCIBILITY of EXPERIMENTAL DATA of COMBINED COOLING/TRAPPING and X-RAY PUMPING SYSTEM

TENTATIVE TIME & FUNDING SCHEDULE

MIREA Tech U

Total: 30 months
$ 3 650 000



COMMENTS to TENTATIVE FUNDING SCHEDULE

MIREA Tech U

Total $ 3 650 000.
Total manhours ~ 60 000
(Average month wage: $ 2 500)

1. ***Choice of proper nuclide and elaboration of technical specifications for all «interstate» R&D roots***

	Subtotal $ 100 000
Labor: 9 months **x** 3 persons **x** $ 2 500/month = (~ 4 450 manhours)	$ 67 500
Materials and expendable supplies =	$ 32 500

2. ***Nuclide production and separation***

	Subtotal $ 750 000
Labor: 18 months **x** 3 persons **x** $ 2 500/month = (~ 8 900 manhours)	$ 135 000
Materials and expendable supplies	$ 300 000
Production expenses =	$ 315 000

3. ***Development of atom medium cooling and trapping***
6. ***Non-radioactive cooled atom medium experiment***

	Subtotal $ 800 000
Labor: 18 months **x** 5 persons **x** $ 2 500/month = (~ 14 900 manhours)	$ 225 000
Equipment, materials, and expendable supplies =	$ 575 000

4. ***Development of pumping processes and X-ray sources***
7. ***Non-cooled nuclei pumping experiment***

	Subtotal $ 900 000
Labor: 18 months **x** 5 persons **x** $ 2 500/month = (~ 14 900 manhours)	$ 225 000
Equipment, materials, and expendable supplies =	$ 400 000
Operation expenses =	$ 275 000

5. ***Development of online diagnostic and control***

	Subtotal $ 350 000
Labor: 9 months **x** 3 persons **x** $ 2 500/month = (~ 4 450 manhours)	$ 67 500
Equipment, materials, and expendable supplies =	$ 282 500

8. ***Test of cooling and pumping processes compatibility***
9. ***Elaboration of Project of Full Scale GRL Experiment***

	Subtotal $ 750 000
Labor: 9 months **x** 8 persons **x** $ 2 500/month = (~ 11 900 manhours)	$ 180 000
Equipment, materials, and expendable supplies =	$ 350 000
Operation expenses =	$ 220 000

The BOTTOM LINE

MIREA Tech U

According to the Contràct statement of work presented ***Program*** was discussed in detail at the Workshop on the Photon-induced Directional Gamma-Emission (PIDGE), which was held at the EOARD Headquarters (Edison House) in London, UK, on May 25-26, 2000.

The main items of the **Workshop Agenda** were as followings:

Thursday, 25 May

Welcome	Col. Gerald O'Connor, EOARD Commander
Objectives of Workshop	Martin Stickley, EOARD, Workshop Chairman
Overview of ***Program***	Lev Rivlin, MIREA
Comments/Brief Presentations on ***Program*** by Attendees	Martin Stickley

Friday, 26 May

Continuation of Yesterdays' Discussion/Presentation	Martin Stickley
Wrap-Up and Future Steps	Agee/Rivlin/Stickley

Separate Group Discussions on Resources Needed for

(A) Isomer Selection and Production,

(B) Development of Atom Medium Cooling and Trapping, and

(C) Development of Pumping Process and X-ray Sources.

Reports by Group Leaders.

Attendance List

Agee, Jack; AFOSR, USA
Andreev, Anatoly V; Moscow Lomonosov University, Russia
Carrol, Jeff; Youngstown State University, Center for Photon Induced Processes, USA
Collins, Carl; University of Texas at Dallas, USA
Degnan, James H; AFRL/DE, USA
Farrel, J. Paul; Brookhaven Tech., USA
Ganciu-Petcu, Mihai; Institute of Atomic Physics, Romania
Howland, Jay; EOARD, USA
Karamian, Sarkis; Flerov Laboratory of Nuclear Reactions, Russia
Kirischuk, Vladimir; Institute for Nuclear Research, Ukraine
Kiuttu, Gerald; AFRL/DE, USA
Kocharovskaya, Olga; Texas A&M University, USA
McDaniel, Patrick; AFRL/DE, USA
O'Connor, Gerald; EOARD, USA
Pouvesle, Jean-Michel, CNRS, GREMI, France
Ries, Nancy; Sandia Labs, USA
Rivlin, Lev A; MIREA Technical University, Russia
Stickley, C.Martin; EOARD, USA
Walker, Phil M; University of Surrey, UK
Zadernovsky, Anatoly; MIREA Technical University, Russia.

The circumstantial discussion of presented detail ***Program*** by all the attendees persuasively testifies that raised complicated scientific and technological problem including a set of preliminary investigations in preparation to a Full Scale GRL Experiment based on the Concept of Recoil Assisted GRL can be successfully solved in relatively short time interval if some experienced scientific groups of different specializations would involved into joined well co-ordinated work.

There is no tasks of second order in this common work: unsuccessful accomplishment of only one of them shall destroy the entire building. It should be emphasized that there is no ready prepared prescription to solve most of sub-problems of the ***Program*** nevertheless of existing broad and firm theoretical and experimental background: high ingenuity and creative power of investigators may play a decisive role.

In this connection it is worth to draw attention to three main keystones to be laid while accomplishing this ***Program*** (see, the separate group list in the Agenda):

(A) *Choice of proper nuclide and its production and separation;*
(B) *Development of atom medium cooling and trapping; and*
(C) *Development of pumping process and X-ray source(s).*

Importance of all these problems (four of nine ones recapitulated in the «Federal» road map) are of fundamental manner but for different reasons (brief presentations by the attendees on selected sub-problems are quoted below).

(A) Evidently a well and lucky choice of working isomer is an indispensable condition for successful beginning the entire ***Program*** and simultaneously an exclusively thorough task if we take into account that both nuclear (longlived metastable level, large cross-sections and moderate photon energies for pumping and lasing processes, *etc.*) and atomic (ability to form a dense atom beam and be cooled by optical laser radiation, *etc*) properties of nuclide should satisfy the very rigid requirements. These requirements are significantly more rigid for the anti-Stokes lasing scheme than for the «two-level» one. So the latter possibly is more preferable for first GRL experiments, nevertheless the anti-Stokes version frequently looks more attractive because as if it consumes nuclear energy stored in metastable isomers for lasing in contrast with the «two-level» scheme which converts into induced gamma-radiation the energy of a pumping source. But evidently this is in a sense merely some example of delusion: in fact all isomeric nuclides which may be considered as candidates for GRL are of the artificial origin and energy of their metastable states is stored by some kind of preliminary external pumping. It should be emphasized that isomer production and energy accumulation in the metastable states are a very complicated and expensive process which demands an enormously large energy expenditure.

Anyway the nuclide choice is a most responsible part of the whole ***Program.***

Carl COLLINS informed that the Center for Quantum Electronics plan for gamma-ray lasers is founded on the judgement that the energy economy of such a device will the most limiting aspect. Regardless of the concept for pumping fundamental considerations of the density of electromagnetic states leading to the Einstein A coefficients compel the loss of major amounts of power at gamma-ray energies into channels of spontaneous loss that will greatly exceed the actual power emitted as a laser radiation. To compensate this power may be the greatest demand for energy economy of the device. To supply that power im real time may be a great difficulty. The uniquely high density of energy stored in nuclear isomers offers an attractive solution. There is possible a «leverage»: in that the application of a small trigger power can release *in situ* order-of-magnitude greater (120 x or greater in case of ^{178}Hf) power. That released energy can benefit various laser schemes by arranging it to compensate the losses mandated by fundamental principles. In the simplest application the triggered isomers would deliver population by cascade into upper laser levels at sufficient rates to compensate the spontaneous losses.

Then Carl Collins reported on a continuing experiments on triggering ^{178}Hf isomers at Center for Quantum Electronics and a study of the optimization of spallation for the production of the ^{178}Hf isomer at the Induced Gamma Emission (IGE) Foundation in Bucharest. The objective of spallation is to maximize the yield of ^{178}Hf and minimize access to the path decaying to the principal longlived contaminant ^{172}Hf. In 2000 with EOARD support IGE Foundation/Dubna will conduct a series of proton irradiations to confirm that the ratio isomer to ^{172}Hf contamination would be improved at lower energies.

Finally Carl Collins emphasized that the future progress might benefit from the critical-path paradigms found in earlier development of other interdisciplinary fields. Specialized «institutes» proved critical in the highly successful stimulation of those fields (LLE at the University of Rochester, NCAR under the «wing» of the University of Colorado). To benefit from the lessons learned with those archetypes it might now be the appropriate moment to identify within the US the National Center for Isomer Research, NCIR. One very cost-effective means for achieving the visibility and momentum accruing from such a step would be to convert the UTD Center for Quantum Electronics into NCIR.

Vladimir KIRISCHUK emphasized that since the production of ^{178m2}Hf isomer obviously is very expensive procedure a detailed theoretical analysis for its optimization must be performed. The calculations of energy dependence for excitation functions and isomer ratios will be done on the basis of cascade-evaporating model or using STAPRE code which will be modified and upgraded. As result a few much promising spallation reactions shall be chosen and the significant amounts of ^{178m2}Hf (today only the UTD Center for Quantum Electronics possesses such amount) would be available for triggering research.

Sarkis KARAMIAN reported on the studies of the productivity of accumulation of the ^{178m2}Hf isomer by the proton irradiation of Ta target at the internal beam of Dubna

synchrocyclotron. Three Ta targets were exposed to the fluence of about 10^{18} protons/cm^2 at the beam energies of 660, 200, and 100 MeV. Many radiactive isotopes and isomers were detected in the irradiated targets by methods of radiochemistry and gamma-spectroscopy. The production yields and mean cross-section values were determined for all the radioactive nuclides as function of the incidence proton energy. The production cross-sections for isomers ^{179m2}Hf, ^{178m2}Hf, and ^{177m}La are flatly dependent on the beam energy. The conclusion has been deduced that irradiation of Ta by 100 MeV protons can serve as a productive and economic way for the isomer accumulation being in many respects better than the targets of high total activity production by the 800 MeV irradiation at the Los Alamos LAMPF facility.

Besides a set of longlived isomers were analysed from the point of view of searching the best candidate for the experiment on induced release of stored energy of metastable states. The isomers of ^{179m2}Hf, ^{178m2}Hf, and ^{177m}La seem to be promising because they have highest excitation energy which makes possible the triggering by soft X-ray irradiation. Unfortunately, the production and isolation of large amounts of Hf isomers remains a difficult and expensive technological problem. Unlike to Hf, the milligram amount of ^{177m}La isomer can be produced by inexpensive method of thermal neutron irradiation in a standard reactor. So the study of the ^{177m}La isomer triggering process is of importance.

Phil WALKER suggested that improved experimental techniques are leading to the discovery of new isomers at excitation energies up to several MeV. These developments suggest the possibility of finding new candidates for forced de-excitation by X-rays and, potentially, optical laser photons. The latter depends on having a sufficient near-by energy level. Therefor, either a chance degeneracy or a high density of states is needed, which is attained at excitation energies of several MeV. The longlived isomers with excitation energies of several MeV are predicted by theoretical calculations. Their high «spin» means that they can still be longlived, even at high excitation energy. New experimental techniques for production and detection are opening up the possibilities to find such isomers. The feasibility to make isomeric atoms into a vapor is most favourable for Lutetium, for instance, a 160-day isomer ^{177}Lu at 1 MeV, which can be made by neutron capture on ^{176}Lu.. There is also evidence for a new longlived isomer at about 3 MeV. A research program to find more examples using the GSI «Experimental Storage Ring» is under way, but it may be year or two before first results emerge.

Solving another two problems [**(B)** and **(C)**] demands an exclusive inventive activity nevertheless that both of them are well developed ones in modern experimental physics. The reason is that some quantitative parameters must be significantly raised comparatively to existing levels. This may demand a usage of quite new approaches.

As regards the preparation of dense and extended nuclei bearing cold atom medium **(B),** main expected difficulties are as followings:

- adaptation of known laser methods of atom cooling to possibly unusual for this methods kinds of atoms which may be chosen to compromise the requirements of nuclear and atom properties (A) and development of optical lasers for corresponding wavelengths;

- proposal and development of methods and setups providing significant increase of cooled atom concentration up to 10^{13} - 10^{14} cm^{-3} and longitudinal extent of trapped fiber-like atom beam up to 100 - 500 cm (*e.g.* usage of non-collinear interaction of atom and laser beams and coherent cooling by counter propagating ultrashort laser π-pulses - for instance, see [4]).

Jeff CARROLL emphasized that after reviewing the necessary concepts needed to achieve a cooled-beam gamma-ray laser, an unbiased scientist would conclude:

(1) No isotope can be definitely identified, but research into isomers and nuclear physics in general is quite advanced. More work must be done, but this area appears to be developing well and should be able to answer the critical questions when the time arises.

(2) No pump source can be definitely identified as being particularly suitable, but research into development of pump sources is in general quite advanced. More work must be done, but this area appears to be developing well and should be able the answer the critical questions when the time arises.

(3) The area of cooling is by far the weakest in terms of its applicability to the gamma-ray laser problem. At present, only a very small set of atoms can be cooled at all using laser techniques (mainly alkali's) and so this greatly restricts the number of isotopes which can be considered for area (1). Likewise, this greatly restricts the types of pump sources to consider. Also, even if an isotope of the restricted set of presently-cooled atoms were suitable, there has never been an experimental demonstration that recoil due to absorption of pump (or pump-like) radiation does indeed produce a discretized velocity distribution. This is absolutely necessary in order to hope to achieve a "hidden" inversion, which in turn is absolutely necessary to produce a gamma-ray laser. Gain without inversion techniques may or may not prove useful in avoiding this problem.

Recommendations:

While funding should continue by which research into areas (1} and (2) would be further advanced, area (3) is the most central to the feasibility of producing a cooled-atom gamma-ray laser. It would be therefore recommended that at the earliest possible stage of the overall project, two milestone experiments should receive primary attention, both in the cooling area.

Experiment (1). The experimental demonstration that laser cooling can be extended to a wider range of atoms. Work in this area is already underway by the

Stanford group of Steven Chu [16] (see also [17]), and results can be expected within one year. The attention of such laser cooling groups must be caught by the gamma-ray laser problem to bear their expertise on the problem.

Experiment (2). Using accelerated ion beams (by which a wider range of atoms/isotopes may be chosen for a test), it must be experimentally demonstrated that a discretized velocity spectrum, with narrow (cooled) lines, can be produced. Without such a demonstration, it is difficult to ensure that a hidden inversion can actually be created. It would be therefore proposed that in the early stages of the project, accelerated research (with a suitable funding level) be applied to the area of laser cooling (blocks 3 and 6 of the Federal Road Map of R&D). It may be necessary to employ a radioactive isotope for experiment (2), depending on the specific parameters which would permit a clear demonstration of the velocity spectrum. It also seems appropriate that block 1 ("Choice of Proper Isomer") be expanded to include a choice of the proper isomer for experiment (2). Such an isomer may be suitable for such a test, yet unsuitable to an eventual gamma-ray laser for other reasons. In addition, the recommendation is that on the "Tentative Time & Funding Schedule," blocks 3 and 6 be placed earlier, and with greater initial funding, than all other blocks except block 1.

These recommendations are made despite their slightly negative impact on the particular area of research at the YSU, which falls mainly into block 4. The cooling area and the limitations it places on choice of isotope/isomer will strongly control the application of any successes in the other block/areas to the gamma-ray laser, no matter how useful those successes may be to other applications (like triggered gamma-ray bursts).

Development of pumping process and corresponding proper X-ray sources **(C)** is a very complicated task too which also demands non-standard improvement activity because, perhaps, no one sample of a variety of existing X-ray machines of different kinds is today up to the mark for pumping requirements (see Comments to «interstate» road map # 4). In fact, for instance,

- Synchrotrons, free electron lasers, wigglers, Compton scatter sources possess excellence beam divergence, but unsufficiently low spectral density and partly small photon energy;

- X-ray plasma lasers have also good beam divergence and extremely high spectral density, but small photon energy, too short pulse duration, and moreover a requirement arises of coincidence of X-ray laser emission- and nuclear absorption wavelenghts which is very infrequent event;

- High density plasma generated by terawatt optical lasers has sufficient spectral density, but too short pulse duration and almost isotropic emission ($\sim 2\pi$);

- Z-pinch liner machines (apparently combined with so called «Hohlraums») feasibly are most adequate candidates possessing high spectral density and

- sufficiently long pulse duration although emission divergence is bad (recent experiments of SANDIA NL [12,13] demonstrated effective radiation «temperature» 300 - 400 eV which corresponds approximately to photon flux spectral density 2.2×10^{13} cm^{-2} s^{-1} Hz^{-1} for 1,5 keV photons); possibly the local spectral density can be increased significantly if the hot plasma is admixed by ions which X-ray characteristic emission lines coincide with pumping photon energies of nuclei [14];

- Possibly some attention should be drawn to recent proposal [11] of a new type of nuclear chain reaction of anti-Stokes radiative transitions of metastable isomer triggered by quasi-equilibrium black- body radiation with high «temperature» which is supported in its part by absorption of gamma-photons emitted by nuclei; resulting intense X-ray burst may be used for pumping.

Anatoly ANDREEV reported on the observation of spontaneous decay of Ta nuclei excited in femtosecond optical laser plasma. The main channels of excitation of isomer states are the absorption of the X-rays emitted in plasma via bremsstrahlung and recombination, the collisional excitation via inelastic scattering of plasma electrons, and inverse internal electron conversion. The 1 mJ laser pulses with 200 fs duration at a 0.6 micron wavelength have been used. The light intensity at a Tantalum target was $2x10^{16}$ W/cm^2. The emitted gamma-quanta were registered by Na(J) detector. Processing the experimental data shows that spontaneous decay time is about 7.5 microsecond, that well corresponds to the known data. Under assumption that the nuclei are excited only in ablated material the excitation efficiency is 10^{-8} to 10^{-7}. However if the possibility of excitation in the surrounding area is taken into account the excitation efficiency is about 10^{-10} to 10^{-9} , which coincides with the theoretical predictions. These experiments have shown that the fs optical laser plasma can be used for the isomeric states excitation . The 1 ps ultrashort X-ray pulse emitted by fs laser plasma is one of the promising sources for development of the «two-level» gamma-laser scheme.

Paul FARRELL informed that the pulsed electron source at the Brookhaven Technology Group provides synchronized electron pulses in the time domain of ~ 300 fs to ~ 100 ps and at fixed energies from ~ 1 MeV to ~ 5 MeV. Beam current is ~ 100 A to 200 A and depends on the pulse duration (~ 3 nC per pulse). Beam brightness is ~ 10^{15} A/m^2 rad^2, which is approximately two orders of magnitude greater than other sources. This source can be used to generate ~ 300 fs bremsstrahlung X-rays or, using relativistic Thompson scattering, it can be used to produce ~ 50 fs pulses or pulse stream of highly tunable collimated photons of very high spectral density. This source could be used to pump shortlived nuclear states. Photon energy range is from ~2 keV to ~ 100 keV. It is important to realize this source is synchronizable and the photons produced are ~ 10^{18} to ~ 10^{20} per sec and the bandwidth is ~ 0.1 % of the nominal energy.

Anatoly ZADERNOVSKY considered a resonant anti-Stokes conversion of the incident broadband X-ray radiation into stimulated gamma-radiation of free isomeric nuclei. The cross-section is calculated for the stimulated anti-Stokes resonant scattering for quanta of different multipolarity as well as the gain coefficient of stimulated gamma-emission in a cooled nuclear ensemble with hidden population inversion. This approach is based on the perturbation theory subjected to some generalization in order to include into consideration the effect of recoil, which is neglected in the case of optical transitions. An isotope screening has been made in order to pick out the candidates with appropriate arrangement of nuclear states. Numerical estimations for selected isomers give the pumping threshold photon flux spectral density of X-ray radiation. Even in the most favourable cases the requirements to the pumping X-ray source remain extremely rigid forcing to pay a particular attention to development a high intensity source of pumping X-ray radiation.

Jean-Michel POUVESLE discussed the optimizing a flush X-ray systems for research on induced gamma-emission. Last results obtained at CQE on the ^{178}Hf target indicate that the different types of flush X-ray systems that have been developed at GREMI, Orleans, France, meet some of the requirements of an ideal device. In the last joint team experiment at CQE it has been demonstrated an enhancement of the fluorescence in the 326 keV line of Hf comprised between 2 and 2.5 %. This corresponds to approximately 600 counts detected over a running period of approximately 10 hours. The actual experimental procedure consists of illuminating the target every 54 s by 90 X-ray pulses of 2.5 ms duration uniformly distributed over a period of 2 s. This means that in the actual operation conditions one can expect an average of one count corresponding to an induced 326 keV gamma-ray photon per burst of 80 X-ray pulses, because at the actual data analyzing only 80 last pulses of each burst are taken into account. Taking into consideration the measurement of the actual X-ray flux at the target, this corresponds approximately to one induced photon for a illuminating flux $4x10^9$ ph/keV cm^2 around 20 keV. This is to compare with the available 10^8 ph/keV cm^2 per pulse around 20 keV at working distance allowed by existing GREMI flush X-ray machine. If one considers that the number of induced photons is strictly proportional to the X-ray flux, a rough estimate indicates that around 40 t0 50 shots of a flush X-ray device would lead to approximately the same result that the presently used system. The main difference being the target illumination time: ~ 1 microsecond instead of 0.2 s. This has a drastic effect on the counting rate coming from the photons produced by spontaneous decay of the Hf isomer. This allows not only a tremendous gain of the signal-to-noise ratio after subtraction of the in-beam and out-beam data, but also leads to significant improvement in the coincidence detection, if the X-ray pulse is shorter than the fast isomer decay. One can see that with device working at kHz frequency the acquisition time can be reduced to few minutes. Experiments at CQE estimated the excitation energy below or around 20 keV. This allows to change the anode material (Fe, Cu, W, Mo....) varying the energy of different L or K lines in the range comprised between 5 to 20 keV to detect any effect closely related to photon production in a given range beside the lower X-ray flux from the continuum. This is possible using adapted pumped X-ray diode. In

the coming year it is proposed to develop and optimize a flush X-ray device well suited for induced gamma-ray emission experiments in various directions:

- optimization of device emitting most below 30 keV;
- reduction of EM noise;
- increase in the repetition rate up to the kHz range;
- increase of the dose per shot at constant repetition rate;
- optimization of various anode materials;
- if possible, burst production at very high frequency (10 to 20 kHz).

Besides these contributions of the separate groups **(A), (B),** and **(C)** mentioned in the Agenda some new proposals were made which cover the eventual free baskets marked above in the ***General Outlook*** by the « ? » signs.

Olga KOCHAROVSKAYA presented the idea of Coherent Optical Laser Control of Nuclear Transitions which presumably may consist in dramatic changes in Moessbauer spectra under the action of laser radiation such as appearing and/or vanishing some of the Moessbauer lines, suppression of absorption, shift and splitting of the lines. . Proposed investigation program is as followings:

1) Proof of principal experiment demonstrating modification of Moessbauer spectra under the action of laser radiation in $^{57}Fe^{3+}$: GaAs and Eu^{2+}: CaS;
2) Demonstration of polarization selective optical pumping of $^{231}Pa^{4+}$: $CsZrCl_6$;
3) Development of Laser-Moessbauer spectroscopy.

Needed funding to arrange the experiment on Eu^{2+}: CaS using existing facility in the Texas A&M University and the experiment on $^{57}Fe^{3+}$: GaAs in Russia =
$ 25 000 for each.

Lev RIVLIN proposed a new concept of the Forced Release of Nuclear Energy Stored in Longlived Isomer [11], which in a sense can be regarded as some kind of nuclear chain reaction. One of the way to perform such a reaction may involve the implementation of a chain set of the anti-Stokes transitions bypassing the strongly forbidden direct decay of metastable states. This demands the absorption of triggering photons which raise more energetic spontaneous transitions mainly in the form of gamma-ray bursts. The energy gain is a positive difference between energy of this spontaneous transition and that of triggering photon. Evidently, this process requires the implementation od closed cycle of self-sustained combustion reaction in which the fraction of the released energy is directed toward triggering new anti-Stokes transitions. The simplest way to launch such a combustion reaction seems to be possible by using nuclides with two pairs of equidistant levels, when emission from one of the spontaneous cascade transitions serves as triggering factor for resonant anti-Stokes transition in nuclei of the same type. Another version may use a mixture of two different nuclides with equidistant levels belonging to nuclei of different types. Discovering of such a remarkable nuclides would be a very pleasant, but infrequent surprise. Therefore one have to try bypass the troubles of resonant transitions using the non-resonant and even the non-radiative versions of the chain reaction. In the non-

resonant radiative case the isomeric nuclei are placed in reaction zone representing a black-body cavity at a temperature *T*. The radiation of those spectral component of the black-body, the energy of which coincides with the triggering energy, excites the trigger states and leads to the spontaneous cascade transitions. The released energy in its part is absorbed by the black-body. This maintains its temperature necessary to stimulate new triggering transitions. So the energy conversion cycle may be closed, if the energy absorbed by the black-body covers or exceeds all possible losses including the emission of thermal radiation and gamma-photon flux into external medium. This radiation absorbed by an envelope maintained at a low temperature represents in essence the useful yield of the whole process. Evidently, such a combustion reaction cannot start from a cold state and hence requires a preliminary ignition. A pair of simple rate equations for the reaction zone temperature *T* and the isomeric nuclei concentration *n* reflects the physical model presented above. What is of importance, the curve *T(n)* representing the steady state solution of these equations is S-shaped. This persuasively shows the feasibility of self-sustained chain reaction. The initial reaction state is specified by the point on the lower stable branch of the S-shaped curve. Then the temperature is rapidly raised by an external ignition source and the mapping point moves upwards unstable branch which represents the reaction threshold. Owing to the instability of this branch the mapping point jumps to the upper stable branch. This jump is accompanied by an avalanche-like increase of temperature and emission of a gamma-quanta burst. Then the temperature decreases and the combustion pulse is over because of burning down the metastable nuclei. It is possible to imagine various ways of the implementation of the high temperature reaction zone, in particular, by employing a hot dense plasma with magnetic or inertial confinement and/or use of so called «Hohlraum» cavity, as well as various sketches of ignition models with exploding wires, terawatt optical lasers and so on. A set of quantitative estimates of considered processes looks quite realistic. One can see the methodological neighbourhood of considered problem both with the problems of inertial nuclear fusion and nuclear gamma-ray lasing. But in a sense a first one is perhaps less complicated than the latter two. It should be emphasized the existence of two important differences: the isomer combustion reaction does not require neither the target super-compression (like the inertial fusion does), nor the deep cooling of nuclear medium (like gamma-ray lasing does). Presented model of the chain combustion reaction of the longlived isomeric nuclei is currently no more than a row idea, but it looks quite productive and is worth to further detail investigation.

Carl COLLINS presented a new Ignition concept which may serves as electromagnetic analog of detonation:

- Each triggered isomer releases >120 x more X-rays;
- Secondary X-rays passing through thick dimensions may be scattered in energy into the trigger transition;
- Secondaries escaping from thin directions will trigger no more isomers;
- Triggering at a single point may suffice to detonate the entire shaped sample;
- The temporal phasing supports traveling-wave amplification, if gain is developed in any transition of the decay cascade.

The extra Nucleus-Photon Interaction Working Group divided recommendations into two groups (Baseline activities and High Risk - High Payoff activities) summarizing the following conclusions:

The Baseline recommendations

1) Continue ^{178m2}Hf triggering activities emphasizing,
    a) Determination of triggering energy level and triggering mechanism;
    b) Temporal and spectral characterizations of triggering output;
    c) Development of independent triggering signatures or approaches to include coincidence measurements, short pulse duration measurements, and other new concepts.
2) Continue work on the Laser-Moessbauer interaction experiment to ensure an adequate funding level to demonstrate the effectiveness of this approach.
3) Develop designs for ^{177}Lu production and triggering experiments to include all radiological considerations.
4) Continue the proposed accelerator production of isomer efforts to include analyzing the outputs of all experiments with nuclear production models so as to guide the search for additional isomers.
5) Perform further study of the isomer chain reaction concept proposed by Prof. Rivlin
6) Perform additional experiments to identify and characterize additional «two-level» gamma-ray laser nuclides.
7) Explore the feasibility of ultrashort pulse (fs) laser production and triggering experiments.
8) Perform triggering experiments on the 25 day half-life isomer of ^{179}Hf.

The High Risk - High Payoff recommendations

1) Investigate and perform fs laser triggering of ^{178m2}Hf.
2) Perform «hohlraum» experiments to determine the feasibility of triggering isomers with black-body spectra.

Finally the PIDGE Workshop adopts the *GENERAL CONCLUSION:*

- **The expanded R&D activity on solving the GRL problem is imperatively recommended;**
- **This activity should be grounded mostly on the physical Concept of the Recoil Assisted Lasing of Free Nuclei; the alternative reasonable physical concepts also are worth to be considered;**
- **Presented *Program* for a set of preliminary investigations (Phase 1) in preparation to a Full Scale GRL Experiment should serve as main guide for the Phase II activity.**

A decisive importance of strong co-ordination of activity of different research groups involved into performing the ***Program*** based on the Concept of Recoil Assisted GRL must be emphasized again. These groups experienced in absolutely different parts of experimental physics (nuclear physics, isomer production, optical lasers, atom beams and deep atom cooling, intense X-ray sources, and so on) and possibly placed in various remote laboratories should elaborate a common working language. They have to learn of making compromises between requirements of different sub-problems to be solved and never say to one another «it is impossible».

References

MIREA Tech U

1. Concept of Gamma-ray Lasing Assisted by Nuclear Recoil Effect. Final Technical Report (May 1, 1999 through Oct. 31, 1999). EOARD Project SPC 99-4036. Contract # F61775-99-WE036.
2. L.A.Rivlin - Quant. Electron., (Moscow), **29**(6), 467-483, 1999.
3. C.S. Adams, E.Riis - Prog. Quant. Electr., **21**(1), 1-79, 1997.
4. L.A. Rivlin, S.D. Yakubovich - submitted to Quant. Electron., (Moscow).
5. C.B. Collins et al. - Phys. Rev. C, **37**, 2267, 1988.
6. C.B. Collins et al. -Phys. Rev. Lett., **82**, 695, 1999.
7. P.B. Hirsch, J.N. Kellar - Proc. Phys. Soc. (London), **B64**, 369, 1951.
8. L. Morton - Appl. Phys. Lett., **9**(5), 194, 1966.
9. L.A. Rivlin, A.T. Semenov - Laser Focus, **17**(2), 82, 1981.
10. E.A.Grigor'eva, A.T.Semenov -Sov. J. Quant. Electron.,(Moscow), **8**,1698, 1978.
11. L.A. Rivlin - Quant. Electron., (Moscow), **30**(6), 2000.
12. J.L. Porter et al. - First Intern. Conf. on Inertial Fusion Sciences and Applications, IFSA'99, 12-17 Sept.1999, Bordeaux, France. Abstracts, p.18.
13. J.S. Lash et al. - *idem,* p.141.
14. V.S. Letokhov - Sov. J. Quantum Electron., **3,** 360, 1973.
15. O.Kocharovskaja et al. - Phys. Rev. Lett., **82**, 3593, 1999.
16. V. Vuletic, S. Chu - Phys. Rev. Lett., **84**, 3787, 2000.
17. D.Mueller at al. - Phys. Rev. Lett., **83**, 5194, 1999